Web Tool User Manual

Overview

The REopt Lite Web Tool evaluates the economic viability of grid-connected solar photovoltaics (PV), wind and battery storage at a commercial site. It allows building owners to identify the system sizes and dispatch strategy that minimize the site's life cycle cost of energy. REopt Lite also estimates the amount of time a PV and/or wind and/or battery and/or diesel generator system can sustain the site's critical load during a grid outage and allows the user the choice of optimizing for energy resilience.

REopt Lite is a free, publicly available web version of the more comprehensive REopt model, which is described in *REopt: A Platform for Energy System Integration and Optimization*. The full REopt model is currently used by National Renewable Energy Laboratory analysts in the provision of project feasibility analysis support to clients. REopt analyses have led to more than 260 MW of renewable energy development.

The REopt Lite Web Tool provides access to a subset of REopt capabilities and allows a broader audience to run site-specific, optimized, and integrated renewable energy decision analyses. This will help accelerate project development and deployment by greatly expanding access to the REopt capabilities, allowing users to implement some of their project feasibility assessments on their own.

Users are cautioned that, although this model provides an estimate of the techno-economic feasibility of solar, wind and battery installations, investment decisions should not be made based on these results alone. Before moving ahead with project development, verify the accuracy of important inputs and consider additional factors that are not captured in this model. See Next Steps and REopt Lite Web Tool Results Caution for important details.

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Intended Users and Use Cases

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Users

The REopt Lite Web Tool is accessible to users with a range of skill levels and data. Inputs are configured so that increasingly detailed input options are progressively exposed to users. Basic users, or those with minimal data, will enter minimal site-specific information to run an analysis. Results will provide an initial, high-level assessment of project feasibility at a site. Advanced users will typically have access to, and will input, detailed site information (e.g., exact tariffs, actual load profiles, actual site area and roof space available, etc.) in order to produce results with a higher degree of accuracy.

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Use Cases

Although a variety of potential uses are possible, the REopt Lite Web Tool is primarily designed to address the following use cases:

Project Development Decision Support

For persons involved in the development and analysis of PV, wind and battery storage projects, the REopt Lite Web Tool will be employed at multiple points during the project development process. In a typical development process, sites are qualified using an iterative analysis approach employing increasing levels of rigor and detail around key input assumptions with each successive iteration. This approach is designed to identify potential fatal flaws as quickly as possible and with a minimum of effort and expense.

Initially, sites are typically screened for feasibility using "desktop" estimates for key project parameters, meaning estimates that can be made using readily accessible information and that do not require a site visit. For example, this approach can include using modeled building loads in lieu of actual site demand data or estimates of available roof space using satellite imagery in lieu of physical surveys of roof layout and condition. In addition, technology parameters, project costs, financing assumptions, and other critical inputs are derived from industry norms and heuristics—actual technology design inputs and quotes from potential vendors and service providers are not solicited at this point in the project development process. The default assumptions for many parameters are sufficient for this initial screening analysis.

Projects without obvious flaws progress through the process, and are reanalyzed using increasing levels of actual site- and technology-specific information. In this case, many of the default assumptions may be overridden with specific values based on more detailed investigation and qualification of the site.

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Research-Related Uses

Persons involved in market development, policy analysis, and research related to the techno-economics of PV, wind and battery storage can use the tool to research the general conditions and factors driving project feasibility. For example, the tool can be used to explore combinations of technology cost and incentive support needed for project feasibility on different building types and under different tariff structures. See For Developers for details on accessing the application programming interface.

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Get Started

The REopt Lite Web Tool communicates with an optimization model via an application programming interface (API). See REopt Technical Reference for a summary and a link to the technical details of the full version of the REopt model. See For Developers for details on API access.

User Dashboard

Upon accessing REopt Lite (https://reopt.nrel.gov/tool), the user has the option of creating or logging into an existing user account via the Log in/Register link in the upper right corner.

REopt Lite can be used without registering or logging in to a user account. However, if a user chooses to set up an account and to log in before running evaluations, their evaluations are saved and can be accessed later.

In order to create a Detailed Custom Electricity Rate, or build a Custom Critical Load profile, or manage typical and critical load profiles, users must be registered and logged into their account.

There are options to create accounts using Google and/or Facebook. Users can create a Google account that is associated with a non-gmail.com address by clicking on “Use my current email address instead”, entering an email address, then following the instructions to verify the ownership of the email address entered. Users signing in with Facebook must be signed into their Facebook account and have platform apps enabled in that account.

Once logged in, the Saved Evaluations button takes the registered user to a dashboard which presents a summary of their stored data from previous evaluations, along with links to view the results page of each of those evaluations in their browser, or copy the evaluation as a basis for creating an edited new evaluation, or to delete the saved evaluation.

The Load Profiles button gives the registered user the option of viewing Saved Typical Loads or Saved Critical Loads. The Typical Load Profiles page presents a button to upload a new load profile and a summary of all previously uploaded typical load profiles, along with lists of the evaluations that used each load profile, a graph of the load profile, and the option to download the profile. Typical load profiles can be deleted if they are not associated with any evaluations. The user must first delete all associated evaluations in order to enable deletion of a typical load profile.

The Critical Load Profiles page presents a button to upload a new critical load profile and another button to build a new critical load profile. The page also provides a summary of all previously uploaded or built custom critical load profiles, along with lists of the evaluations that used each critical load profile, a graph of the load profile, and the option to download the profile. Typical load profiles can be deleted if they are not associated with any evaluations. The user must first delete all associated evaluations in order to enable deletion of a typical load profile.

The Custom Rates button takes a registered user to a list of previously defined custom electricity rate, or allows them to define a new electricity rate.

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New Evaluation

The Step 0 section details the advantages of the optional registration and logging in a private account, including the ability to save evaluations, create custom electricity rates, build custom critical load profiles, and manage saved typical and critical load profiles. It also lists the data that should be gathered for different types of evaluation. A Financial evaluation will require site location, electricity rate, and either a custom load profile or the combination of a building type and an annual energy consumption estimate for that building. A Resilience evaluation will require these data plus data defining a planned or potential electric outage. The extra Resilience data includes a way of determining the load that will need to be met in an outage: either a percentage critical load factor, a custom critical load profile, or the critical load components that would be required in an outage that can be used to build a critical load profile. The other key data are the expected or desired outage duration to be survived and a starting date and time for the outage. If a generic potential outage is to be modeled, then a worst-case scenario can be used by selecting the outage start time as the peak time of the critical load profile.

The first step in creating a new evaluation is selecting the focus of the analysis—whether to optimize for financial savings or energy resilience. The default selection is financial savings. If Financial is selected, then Resilience inputs are hidden.

The second step is entering site-specific data for the scenario that the user wishes to evaluate. This data includes the location and electricity rate and consumption details, as well as financial constraints. A variety of inputs are necessary for a REopt Lite analysis, but the tool provides editable default values for most of these parameters.

The third step is selecting the technologies to be included in the analysis—whether to evaluate PV alone, wind alone, battery alone, or any combination of these technologies together. If a Resilience evaluation has been chosen, a diesel generator evaluation is also given as an option. Because the wind evaluation can run into time constraints, it is not included in the default selection of PV and Battery technologies. Only the inputs for a selected technology are visible. Inputs for any technology that is not selected are hidden.

For a financial savings optimization, there are three required inputs that the user must enter. Two of these entry fields are displayed in the Site and Utility Inputs section when the tool is first opened. These two inputs are Site Location and the applicable Electricity Rate for that site location. The third required input is the Typical load—entered either as a Simulated Building Type plus an annual Energy Consumption or as a Custom Load Profile data file upload—entered in the Load Profile section.

For an energy resilience optimization, there are four additional required inputs. The first is the Critical energy load profile—entered either as a Critical load factor percentage, as a Custom critical load profile data file upload, or as a custom built critical load—in the Load Profile section. The final three required inputs are the Outage duration, Outage start date and Outage start time for the grid outage that the resilience optimization will model.

There are a total of seven possible Data Input sections: Site and Utility, Load Profile, Resilience (visible only when the Resilience optimization is chosen), Financial, PV, Battery, Wind, and Generator (also visible only when the Resilience optimization is chosen). As each section is expanded, the key driver input parameters for that Data Input section are displayed. In most cases these top inputs in each section will have the greatest impact on the results of the evaluation. Additional parameters in each section can be displayed by selecting the “Advanced inputs” option.

Parameters with default values have these prepopulated values displayed in light gray text in the data entry boxes. All of these values can be overridden, and those that have been altered by the user will display in a darker text and the default will be displayed in the right margin next to the input box. Each separate section, as well as the entire form, has an option to reset the parameters to default values. See REopt Lite Web Tool Default Values for details and explanations of these values.

When all desired inputs have been entered and/or edited, the final step is to select the Get Results button. A new page will display while the tool is optimizing the results. This may take up to several minutes to complete, depending on the complexity of the analysis. The Results page displays recommended system sizes, potential savings, the system dispatch strategy returned from the API, and, if requested, analysis of resilience system economics. The user will have the option of downloading a dispatch spreadsheet and a proforma spreadsheet and of running an outage simulation. The user can also return to the input page to edit the inputs and alter the scenario for a new evaluation.

The results provided by the REopt Lite Web Tool assume perfect prediction of both solar irradiance, wind speed, and electrical load; in practice, actual savings may be lower, depending on the battery control strategy used in the system and the accuracy of the solar irradiance, wind speed, and load predictions. The PV system performance predictions are calculated by PVWatts®, include many inherent assumptions and uncertainties, and do not reflect variations between PV technologies nor site-specific characteristics except as represented by inputs. Wind performance predictions are approximate only and do not include the significant impact of obstacles surrounding the turbine that could block the wind flow. When modeling an outage the results also assume perfect foresight of the impending outage, allowing the battery system to charge in the hours leading up the outage. See REopt Lite Web Tool Results Caution for important details.

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International Use

Although REopt Lite is designed for use with locations within the United States, there is a link in the upper right corner, to the left of the Log In/Register link, that provides suggestions for adjustments that can allow the use of most of the tool's features for international locations.

Site Location & Utility Rate
Selecting a site location outside the US will prompt a message that no electricity rates can be found for the location. This is because the utility rate database used by REopt Lite does not include international locations. However, custom utility rates can be entered as simple annual or monthly rates. Detailed rates, with variable prices dependent on times and months, can also be entered if the user is registered and logged in to a user account. Details of rate structures for some international locations can be found at the International Utility Rate Database.

Currency

Currency values are all in US dollars. Conversions from the local currency to USD can be made for inputs of utility rates, system costs, and incentive values. Conversion of the final results of the evaluation will then be necessary, from USD back to the local currency. One popular tool for currency conversion approximation is the XE Currency Converter.

Load Profile
The Load Profile option for simulated load data is based on US building and climate area data. If this simulated load option is used, the simulated load profile should be checked for reasonableness for the climate of the selected location.

Financial Info
Financial, tax and incentive input defaults in all sections need to be carefully considered and altered to match local tax and interest rates and available financial incentives. Default costs for technology systems are also based on typical costs in the US. Resources for researching international renewable energy costs can be found at the International Renewable Energy Agency.

Solar Production Data
Solar production data is taken from the PVWatts® dataset, which includes many international locations. REopt Lite will use the closest available location that is found to have resource data, so the user should independently confirm that PVWatts includes data for a location that is acceptably close to their site location. The available resource data locations can be found using NREL's PV Watts.

PV System Characteristic
PV System Characteristic defaults need to be altered for locations in the southern hemisphere. The Array azimuth for maximum insolation should be changed from 180° to 0°. The Array tilt for fixed ground mount systems will default to the site's latitude, which will be a negative number that will need to be changed to a positive number in order to avoid an error.

Wind Resource Data
Wind systems can't currently be modeled from the webtool user interface for international locations due to lack of international wind resource data. However, if the user has hourly wind resource data for their site, they can use this data in the application programming interface (API), instead of the webtool interface, to complete an optimization.

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REopt Lite Web Tool Data Inputs

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Site and Utility Inputs

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Site location

 - *The Site Location may be entered as a street address, city, state or zip code. The dropdown menu will populate as you type and a location must then be selected from this menu.* ***This value is required.*** *The location is used to determine solar and wind resource data and applicable utility rates. Solar and wind resource and utility rate data is available for locations in the US.*

Once the location is typed into the form, the matching location selection must be chosen from the dropdown menu in order to load the Electricity Rate options menu in the data entry field below. Currently, the location must be within a state in the United States—the required menu of electricity rates will be inaccessible for foreign and U.S. territory locations. However, options are given for using the tool for international use.

Use sample site option: If the *Use sample site* link is selected, and confirmed in the resulting popup, inputs for site location, an electricity rate and a simulated load profile for a sample location are populated. If a Resilience optimization has been selected, required outage inputs in the Resilience section must still be chosen.

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Electricity rate

 - *The electricity rate can be selected from a list of rates available in the location entered. The rates are downloaded from the* Utility Rate Database (URDB)*. If available, the most common* *rates are listed at the top of the list. Due to data limitations in some parts of the country, the full list of rates includes rates available within 25 miles of the location specified. **This value, or a custom annual, monthly or detailed rate, is required**. Utility rates that are not in URDB can only be modeled as custom rates.*

The URDB provides rates for most locations that are within a state in the United States, but not those in a foreign country or U.S. territory. If no electricity rate is found in the URDB for the site location entered, this message will appear: “No electricity rates were found for the location you entered. Please try another location nearby”. In this case, substituting a neighboring city as the site location will often return a valid list of rate options from the same utility that serves the original location selected.

☐ - A custom electricity rate can be created by selecting the box.

If the electricity rate will stay constant through the year, select the “Annual” option and enter the $/kWh Energy cost and, if relevant, the $/kW Demand cost. If an “annual” demand charge is specified, it will still be applied on a monthly basis.

If the electricity rate varies by month during the year, select the “Monthly” option and enter the $/kWh Energy cost and, if relevant, the $/kW Demand cost that apply in each month of the year.

If the electricity rate varies during a single month, such as a rate with weekday/weekend or time-of-use rate differences, select the Detailed option. You must be registered and logged in to a user account to access this feature. A tool will open where you can enter different rates for different time periods, along with time and month schedules for applying these period rates. Once you have named, created, and saved detailed custom rates, they will show up in the “Select Custom Rate” dropdown menu on the main input page and they can be selected to be applied to a current optimization.

The custom electricity rate allows for modeling some utility rates that do not appear in the URDB, but, currently, can only be chosen as a substitute for the URDB rates and not as an additional add-on charge to a URDB rate.

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Custom Rate Builder: New Custom Rate

This Custom Electricity Rate Builder allows you to create a detailed custom electricity rate that varies by time period.

- Start by entering a name for the custom rate. Once you have named, created and saved detailed custom rates, these names will show up in the "Select Custom Rate" dropdown menu on the main input page and can be selected to be applied to an optimization. An optional description can also be entered in order to assist in identifying a custom rate.
- Enter each separate rate into the Rate Periods tables for both Energy Charges and Demand Charges. If the rate for a time period includes usage tiers, add tier(s) to that period and enter the maximum energy purchases allowed in the tier(s). The final tier will have unlimited maximum usage.

- After you have defined the Rate Periods, use the Weekday and Weekend Schedule Tables to select the months/times when each period applies. When you have selected a block of time cells, a popover will appear with a dropdown menu so that you can select the relevant period for those cells.

Period
*□ - Periods do not have to be sequential; however, **tiers within a given period must be sequential.***

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Custom Rate Builder: My Custom Rates Summary

This Custom Electricity Rate Manager allows you to view, edit, and copy the detailed custom electricity rates that you have created.

NOTE: Once a custom rate has been used in an optimization, that particular rate can no longer be edited or deleted. However, the rate can be copied to create a new or corrected rate.

The table lists your custom rates in chronological order in which they were created. The name and description you assigned are listed in the table along with the maximum and minimum charges. If you wish to look at the details of the rates by time period, click on View Charge Periods.

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Net metering system size limit (kW)

*□ - The net metering limit determines the maximum size of total systems that can be installed under a net metering agreement with the utility. Projects sized up to the net metering limit will receive credit for any exported energy at the electric retail rate at the time of export. Projects sized greater than the net metering limit will receive credit at the wholesale rate for any energy exported. Information on state net metering limits is available at www.dsireusa.org. **The user is not required to enter a value for this input. By default, REopt Lite assumes that net metering is not available (net metering limit = 0).***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

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Wholesale rate ($/kWh)

□ - The wholesale rate for exported energy applies to projects that are not net metered, or projects sized greater than the net metering limit. If a wholesale rate is entered and net metering is not available (i.e. net metering size limit is 0 kW) or if the project is sized greater than the net

metering limit, then the project will receive credit for any exported energy at this wholesale rate, up to the annual site load so that the site does not become a net exporter of electricity. ***This value is not required****.*

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Site name

 - *A site name may be entered here.* ***This field is not required****.*

This field allows the user the option to give the scenario a distinct name to distinguish various sites and scenarios. This is especially useful for Registered and logged-in users who will see the Site Name that they have assigned in the Saved Evaluations table.

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--- Advanced inputs

Land available (acres)

 - *Land available is the number of acres available for PV or wind. This input is used to limit the amount of PV or wind recommended at the site. PV size is constrained by land area available, assuming a power density of 6 acres per MW. Wind size is constrained by land area available, assuming a power density of 30 acres per MW for turbine sizes above 1.5 MW.* ***This value is not required.*** *The default value is unlimited, meaning PV or wind size is not limited by land area available.*

The maximum number entered must be less than or equal to 1,000,000—an error will display if a higher value is entered.

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Roofspace available (sq ft)

 - *The roof surface area available on-site, in square feet, for solar panels. This input is used to limit the amount of PV recommended at the site. For more accurate results, exclude areas known to be consistently shaded. PV size is constrained by roof area available, assuming a power density of 10 DC-Watts/ft^2.* ***This value is not required.*** *The default value is unlimited, meaning PV size is not limited by roof area available.*

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Note that there is an option in the right margin of the Site and Utility Information section to “Reset to default values”. See REopt Lite Web Tool Default Values for information on default values.

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Load Profile Inputs

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Typical load

 - *If "Simulate" is selected, the type of building is used in combination with annual energy consumption to simulate a load profile. If "Upload" is selected, the user can upload one year of hourly, 30-minute, or 15-minute load data.*

The user is given a choice between creating a Simulated Load Profile and uploading a Custom Load Profile. **One of these two load profile options is required**. If Upload is not selected, the tool uses a Simulated Load Profile and entries are required for Type of Building and Annual Energy Consumption in order to complete the simulation calculations. Note that a default Annual Energy Consumption value will be provided that corresponds to the Site Location and Type of Building chosen. This default can be overridden with a custom value.

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Simulate

Directly below the box containing the Simulate inputs, there are links to "Download typical load profile" and to "Chart typical load data" for the simulated load that has been selected. The typical load profile downloads as a .csv file. There is a slider under the chart of typical load data that can be used to zoom in on a selected section of the chart or navigate within the chart.

Type of building

- If a custom load profile is not uploaded, the type of building is used in combination with annual energy consumption to simulate a load profile. Select the building type from the drop-down menu. The loads are generated from DOE's post-1980 commercial reference building models for the climate zone of the site using EnergyPlus simulation software, and scaled based on the annual energy consumption. Note that this scaling method may be more accurate for some building types and end-uses than others. ***This value is required if a custom load profile is not uploaded.***

The 16 building types modeled are:

BUILDING TYPE NAME	***FLOOR AREA (FT^2)***	***NUMBER OF FLOORS***
Large Office	*498,588*	*12*
Medium Office	*53,628*	*3*
Small Office	*5,500*	*1*
Warehouse	*52,045*	*1*
Stand-alone Retail	*24,962*	*1*
Strip Mall	*22,500*	*1*
Primary School	*73,960*	*1*
Secondary School	*210,887*	*2*
Supermarket	*45,000*	*1*
Quick Service Restaurant	*2,500*	*1*
Full Service Restaurant	*5,500*	*1*
Hospital	*241,351*	*5*
Outpatient Health Care	*40,946*	*3*
Small Hotel	*43,200*	*4*
Large Hotel	*122,120*	*6*
Midrise Apartment	*33,740*	*4*

The 16 climate zones used to create the reference buildings are:

CLIMATE ZONE	***REPRESENTATIVE CITY***
1A	*Miami, Florida*
2A	*Houston, Texas*
2B	*Phoenix, Arizona*
3A	*Atlanta, Georgia*
3B-Coast	*Los Angeles, California*
3B	*Las Vegas, Nevada*
3C	*San Francisco, California*
4A	*Baltimore, Maryland*
4B	*Albuquerque, New Mexico*

4C	*Seattle, Washington*
5A	*Chicago, Illinois*
5B	*Boulder, Colorado*
6A	*Minneapolis, Minnesota*
6B	*Helena, Montana*
7	*Duluth, Minnesota*
8	*Fairbanks, Alaska*

Dropdown menu options include the 16 modeled building types, plus a flat load option—for a site with a constant electric load.

More information can be found at https://energy.gov/eere/buildings/commercial-reference-buildings.

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Annual energy consumption (kWh)
□ - Either the default value or a custom annual consumption value is required if a custom load profile is not uploaded.

If a custom load profile is not uploaded, the site's total annual energy usage (in total kWh) is used in combination with the building type to simulate a load profile. Default values are based on the DOE commercial reference building model for that building type / climate zone. These defaults can be overridden with a custom Annual energy consumption value. ***This value is required if a custom load profile is not uploaded.***

The default annual consumption populates based on both the building type and climate zone for the location given. Warning: the climate zones used correspond to United States climate areas. If the tool is being used for international location evaluation, the climate zone that is used to calculate a default energy consumption may not be a good match to the international location. Care should be given to determine if a default provided is appropriate before using it. The maximum number entered must be less than or equal to 1,000,000,000,000—an error will display if a higher value is entered.

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Upload

Directly below the box containing the Upload inputs, there is a link to "Chart typical load data" for the load profile that has been uploaded. There is a slider under the chart of typical load data that can be used to zoom in on a selected section of the chart or navigate within the chart.

Custom load profile
□ - If "Upload" is selected, the user must upload one year (January through December) of hourly, 30-minute, or 15-minute load data, in kW, by clicking the browse button and selecting a

file. A sample custom load profile is available, which includes an optional header and optional additional column A with the 8760 hour intervals listed for reference.

The file should be formatted as a column of 8760, 17,520, or 35,040 rows. The file should be saved as a .csv file. If the file is not the correct number of rows (8,760, 17,520, or 35,040), or there are rows with blank entries, the user will receive an error message. If the available load data is for a leap year, please delete the data for December 31 to shorten the file length to 8,760, 17,520, or 35,040 rows.

The option for using 15-minute or 30-minute load data is provided for user convenience, not for higher model resolution. If 15-minute or 30-minute data is uploaded, it will be down-sampled to hourly data for the evaluation

If the load profile is from a leap year, where an extra day's worth of data is part of the file, the December 31 data should be deleted so that the file will be the correct length. Deleting December 31 will have the least impact on the evaluation results. The February 29 data should not be deleted, because it would impact the day of the week status for days in all of the weeks from March to December, and many utility rates have different rates for weekdays and weekends.

Year of load profile

 - *Enter the calendar year the load profile represents. This information is needed to correctly apply tariffs that vary by days of the week.*

The default for this input is the current year.

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Critical load

 - *If "Percent" is selected, the critical load is a percentage of the typical load profile. If "Upload" is selected, the user can upload one year of hourly, 30-minute, or 15-minute critical load data. If "Build" is selected the user can create a custom critical load profile based on specified load components. Only the one active option for specifying the critical load will be applied to the optimization.*

Critical energy load is the load that must be met during a grid outage. It can be calculated as a consistent percent of the typical load profile that is being used, uploaded as a separate custom load profile, or built specifically to correspond to important loads at the site. **One of these three load profile options is required**.

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Percent

Directly below the box containing the Percent input, there are links to “Download the critical load profile” and to “Chart critical load data” for the percent of the simulated or custom load that has been selected. The typical load profile downloads as a .csv file. There is a slider under the chart of typical load data that can be used to zoom in on a selected section of the chart or navigate within the chart.

Critical load factor

□ - The percent of typical load that must be met during a grid outage. This factor is multiplied by the typical load to determine the critical load that must be met during the specified outage period. Units: decimal percent. ***This value is required if “Percent” is chosen.***

The default for this input is 50%.

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Upload

Directly below the box containing the Upload input, there is a link to “Chart critical load data” for the critical load profile that has been uploaded. There is a slider under the chart of typical load data that can be used to zoom in on a selected section of the chart or navigate within the chart.

Custom critical load profile

□ - If “Upload” is selected, the user must upload one year (January through December) of hourly, 30-minute, or 15-minute load data, in kW, by clicking the browse button and selecting a file. A sample custom load profile is available, which includes an optional header and optional additional column A with the 8760 hour intervals listed for reference.

The file should be formatted as a column of 8760, 17,520, or 35,040 rows. The file should be saved as a .csv file. If the file is not the correct number of rows (8,760, 17,520, or 35,040), or there are rows with blank entries, the user will receive an error message. If the available load data is for a leap year, please delete the data for December 31 to shorten the file length to 8,760, 17,520, or 35,040 rows.

The option for using 15-minute or 30-minute load data is provided for user convenience, not for higher model resolution. If 15-minute or 30-minute data is uploaded, it will be down-sampled to hourly data for the evaluation

For load profiles for leap years, where an extra day’s worth of data is part of the file, the December 31 data should be deleted. This will have the least impact on the evaluation results. February 29 data should not be deleted, because it would impact the day of the week status for days in all of the weeks from March to December, and many utility rates have different charges for weekdays and weekends.

The year of the Custom critical load profile is assumed to be the same as the year set for the Custom Load profile.

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Build

The dropdown menu contains all of the critical loads profiles that the user has built and saved. One of the options in the dropdown menu must be selected in order to be used in the optimization. To build a new critical load profile, the registered and logged can click the “Build New Critical Load Profile” link and build a new load in the resulting pop-up window, while retaining the other inputs already entered. Alternatively, the user can click “Build, copy, and manage your critical load profiles” below the blue box, or “Critical Loads” in the top right hand corner of the webpage and be taken to a different page to either copy and edit a previously built critical load or to build a new critical load profile from component electrical loads. If the user chooses either of these options, a new evaluation must be started and all inputs that had been entered for the current optimization will need to be re-entered.

Critical load profile from custom build
□ - You must be registered and logged in to a user account to access this feature. The Critical Load Builder allows you to create a daily emergency load profile by building a list of equipment that is critical at your site - along with wattage, quantity, daily operation hours, and annual operation months. Once you have named, built and saved critical load profiles, they will be available for selection from the Critical Load Profile dropdown menu on the main input page, and can be used in an optimization. This tool is based on SolarResilient, a tool developed by Arup, under contract to the Department of the City and County of San Francisco, with funding from the Department of Energy.

The year of the Custom critical load profile is assumed to be the same as the year set for the Custom Load profile.

Directly below the box containing the Build input, there are links to “Download the critical load profile” and to “Chart critical load data” for the percent of the simulated or custom load that has been selected. The typical load profile downloads as a .csv file. There is a slider under the chart of typical load data that can be used to zoom in on a selected section of the chart or navigate within the chart.

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Critical Loads Builder: New Critical Load

The Critical Load Builder allows you to create a daily emergency load profile by building a list of equipment that is critical at your site - along with wattage, quantity, daily operation hours, and annual operation months. This tool is based on SolarResilient, a tool developed by Arup, under contract to the Department of the City and County of San Francisco, with funding from the Department of Energy.

To build a critical load profile:

- Start by entering a name for the Critical Load Profile. Once you have named, built and saved critical load profiles, they will be available for selection from the Critical Load Profile dropdown menu on the main input page, and can be used in an optimization.
- Select load components from the dropdown list. The load component will populate with default suggestions for the power, hours, and months.
- Once added, you can edit the details of the load component to better simulate your critical load conditions.
- Add as many load components as necessary. The last load in the dropdown menu is a custom load, which can be used as a start point to add components that are not in the menu.

Note that these components are being modeled as flat loads at the power specified, and during the operation times specified by the user. There is no cycling, for example, on the air conditioner or space heater. The load does not change based on the weather or room temperature.

Load Type

□ - Select a pre-existing load type and add the load component to your new critical load profile. Once added, you can edit the details of the load component to best simulate your critical load conditions. Add as many load components as necessary.

Power (W)

□ - This is the power requirement for the selected load type. Default values are taken from Lawrence Berkeley National Laboratory's Home Energy Saver Engineering Documentation*, the Energy Star* Data Sets*, and the DOE Appliance and* Equipment Standards Program Database*. Many appliances have the wattage stamped on the unit, representing the maximum power drawn by the appliance. The wattage can also be estimated by multiplying the electric current draw, in amperes, by the voltage used by the appliance (typically 120 volts). Amperes may be stamped on the unit, or listed in the owner's manual. Energy.gov also provides a* calculator for estimating appliance and electronic energy use*.*

Start Hr.

□ - Start hour is represented similar to military time. For example, 0 represents 12:00 AM and 16 represents 4:00 PM. To simulate a component that would run all day, the start hour would be 0 and the end hour would be 24. To simulate a component that runs from 3:00 AM to 5:00 PM the start hour would be 3 and the end hour would be 17. The start hour must be a whole number and cannot be greater than 23 (representing 11:00 PM).

End Hr.

□ - End hour is represented similar to military time. For example, 1 represents 1:00 AM, 13 represents 1:00 PM, and 24 represents 12:00 AM ***on the following day****. To simulate a component that would run all day, the start hour would be 0 and the end hour would be 24. To simulate a component that runs from 3:00 AM to 5:00 PM the start hour would be 3 and the end hour would be 17. The end hour must be a whole number and cannot be less than 1 (representing 1:00 AM).*

End Month
□ - To specify a load component duration of one month, select the same start month and end month.

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Critical Loads Builder: My Critical Loads Summary

This Critical Load Profiles summary allows you to view, edit, and copy the critical load profiles that you have built.

NOTE: Once a critical load profile has been used in an optimization, that particular load profile can no longer be edited or deleted. However, the load profile can be copied to create a new or corrected load profile.

The table lists your critical load profiles in the chronological order in which they were created. The name and description you assigned are listed in the table along with the minimum, average, and maximum loads. The dates for the minimum and maximum load values refer to the first chronological instance of that minimum or maximum load. If you wish to look at the details of the critical load profiles by time period, click on the icon to View Load Profile Components. Icons are also available to chart or download the critical load profile.

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Resilience Inputs

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By default, the REopt Lite Web Tool optimizes systems to maximize grid-connected economics. Users have the option of specifying additional resilience requirements to design a system that will sustain a critical load for a specified outage period.

Outage duration (hours)

□ - The number of hours the outage lasts. The system will be sized to minimize the lifecycle cost of energy, with the additional requirement that it must also sustain the critical load during the outage period specified. ***This input is required to complete the optimization for energy resilience. The input must be a number between 0 and 8759****.*

The maximum number entered must be less than or equal to 8,759—an error will display if a higher value is entered.

If extra data is desired on typical outages in the US, the user can check the Electric Power Monthly, which is the US Energy Information Administration's compilation of location, duration and description of major electric disturbances by month.

Outage start date

□ - The date that the outage starts. The system will be sized to minimize the lifecycle cost of energy, with the additional requirement that it must also sustain the critical load during the outage period specified. ***This input is required to complete the optimization for energy resilience. An outage start date must be selected between January 1 and December 31****.*

In general, selecting an outage start date when the site's load is higher (often summer) will result in larger system sizes that can sustain the critical load during more outages. Selecting an outage period during a time of year when the site's load is lower will result in smaller system sizes that sustain the critical load during fewer outages. However, solar and/or wind resource will also impact the resiliency of the system.

View critical load profile link

□ - Click on this link to open a popup of the critical load profile. There is an option to automatically populate the Outage Start Date and Outage Start Time fields with the date and time of the maximum load by clicking Start Outage On Peak.

Outage start time

□ - The hour of day that the outage starts. The system will be sized to minimize the lifecycle cost of energy, with the additional requirement that it must also sustain the critical load during the outage period specified. ***This input is required to complete the optimization for energy resilience. An outage start time must be selected between 12 am and 11 pm****.*

Back to Resilience Inputs

Type of Outage Event

□ - The selection made in this input will not impact the optimization results or net present value calculation for the project. It will affect only the results presented in the Effect of Resilience Costs and Benefits section where Avoided Outage Costs and NPV after Microgrid Costs and Benefits are presented.

If Major Outage – Occurs once per project lifetime is selected, the avoided outage costs are calculated for a single outage occurring in the first year of the analysis. This is the default selection. If Typical Outage – Occurs annually is selected, the outage event is assumed to be an *average outage event that occurs every year of the analysis period. In this case, the avoided outage costs for one year are escalated and discounted to account for an annually recurring outage.*

Note that there is an option at the bottom of the Resilience section to "Reset to default values." See REopt Lite Web Tool Default Values *for information on default values.*

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Financial Inputs

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Host discount rate, nominal (%)

* - The nominal rate at which the host discounts the future value of all future costs and savings. Note this is an after tax discount rate if the Host is a taxable entity. Units: decimal percent. **This value is not required**.*

The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

This is a key driver input.

Back to Financial Inputs

Electricity cost escalation rate, nominal (%)

* - The expected annual escalation rate for the price of electricity provided by the utility over the financial life of the system. Units: decimal percent per year. **This value is not required**. For federal analysis, values are provided in the* Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis, Annual Supplement to NIST Handbook 135.

The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

This is a key driver input.

Back to Financial Inputs

--- Advanced inputs

Analysis period (years)

□ - The financial life of the project in years. Salvage value is not considered. Units: years. ***This value is not required****.*

The analysis period must be at least 5 years and at most 75 years—an error will display if a value outside this range is entered.

Back to Financial Inputs

Host effective tax rate (%)

□ - The percent of income that goes to tax for the system host. Units: decimal percent. ***This value is not required.***

The tax value default is currently 26%. This value is the sum of a 21% federal rate plus a 5% state average rate. The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

Back to Financial Inputs

O&M cost escalation rate, nominal (%)

□ - The nominal expected annual escalation rate for O&M costs over the financial life of the system. Units: decimal percent. ***This value is not required.***

The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

Note that there is an option in the right margin of the Financial section to “Reset to default values”. See REopt Lite Web Tool Default Values for information on default values.

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PV Inputs

If “PV” or “Both” is selected for “Do you want to evaluate PV, battery, or both?” in the first step, then the PV technology inputs are enabled. Conversely, if only “Battery” is selected, then all PV inputs remain hidden.

System capital cost ($/kW)

□ - Fully burdened cost of installed PV system in dollars per kilowatt. ***This value is not required.***

The maximum number entered must be less than or equal to 100,000—an error will display if a higher value is entered.

This is a key driver input.

Back to PV Inputs

Existing PV System?

This checkbox allows the user to consider an existing PV system in the Resilience optimization.

Existing PV system size (kW):
If the site has an existing PV system, enter its size in kW. The existing PV system will be factored into Business as Usual O&M cost calculations and net-metering credits and limits. No incentives will be included for the existing PV system. If the user has chosen to optimize for energy resilience, the energy from this existing PV system will be factored into the energy Resilience optimization.

Type of load profile:
Select how the typical energy load profile will be characterized with the addition of the existing PV system load. The default selection is Net load profile, which is the gross (or native) load minus the existing PV generation. The other option is to consider the typical energy load profile that has been entered as the Gross load (also known as native load).

Back to PV Inputs

Capital Cost Based Incentives

□ - Federal, State, and Utility capital tax credits and incentives can be entered in this table. Each incentive can either be entered as a percentage of capital cost, with a maximum dollar

amount, or as a rebate per kW, with a maximum dollar amount. Incentives are considered in the following order; utility, state, then federal. For example, if there is a 20% utility incentive and a 30% state incentive, the 20% utility incentive would be applied first, then the 30% state incentive would be applied to the reduced cost. The incentives are not additive, that is, the site would not get a 20% + 30% = 50% discount. The default value for federal capital cost based incentive is the 26% business energy investment tax credit. Look up additional incentives at www.dsireusa.org.

Percentage-based incentive (%)
*- Incentives given as a percentage of capital costs. The federal percentage-based incentive is treated as a tax-based incentive to model the federal investment tax credit. All other incentives are not tax-based. Units: decimal percent. **This value is not required.***

The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

Maximum incentive ($)
*- The maximum dollar value of the percentage based incentives. If there is not a maximum, the value defaults to 'Unlimited'. **This value is not required.***

A maximum incentive amount can be specified for State and Utility incentives. The federal incentive maximum is set as unlimited. The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Rebate ($/kW)
*- Rebates offered based on installed system size. **This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Maximum rebate ($)
*- The maximum dollar value of the rebate, if there is not a maximum, the value defaults to 'Unlimited'. **This value is not required.***

A maximum rebate amount can be specified for State and Utility level incentives. The federal incentive maximum is set as unlimited. The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

The incentives are key driver inputs.

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Production Based Incentives

- Federal, State, and Utility production incentives can be entered here. If there is more than one production based incentive offered, the combined value can be entered and should be discounted back to year one if the incentive duration differs. Look up incentives at www.dsireusa.org.

Production incentive ($/kWh)
□ - The dollar value of the incentive per kWh produced. ***This value is not required.***

The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

Incentive duration (yrs)
□ - The number of years the production incentive is awarded. ***This value is not required.***

Maximum incentive ($)
□ - The maximum incentive amount awarded each year; if there is no limit, the value defaults to 'Unlimited'. ***This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

System size limit (kW)
□ - The maximum system size eligible for the production based incentive; if there is no limit, the value defaults to 'Unlimited'. ***This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

The incentives are key driver inputs.

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--- Advanced inputs

PV Costs

O&M cost ($/kW per year)
□ - Estimated annual PV operation and maintenance (O&M) costs per installed kilowatt. O&M includes asset cleaning, administration costs, and replacing broken components. It also includes the cost of inverter replacement. ***This value is not required.***

The maximum number entered must be less than or equal to 1000—an error will display if a higher value is entered.

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PV System Characteristics

Minimum size desired
Maximum size desired
Module type

Array type
Array azimuth
Array tilt
DC to AC size ratio
System losses

Back to PV Inputs

Minimum size desired (kW DC)
□ - REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The minimum system size forces a system of at least this size to appear at the site. If there is not enough land available, or if the interconnection limit will not accommodate the system size, the problem will be infeasible. The default value is 0 (no minimum size). The number entered for the minimum size desired may not be identical to the maximum size desired. If a specific sized system is desired, for example 100 kW, please enter 100 as the minimum size and a slightly larger number, such as 100.000001 as the maximum size. ***This value is not required.***

Maximum size desired (kW DC)
□ - REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The maximum size limits the PV system to no greater than the specified maximum. To remove a technology from consideration in the analysis, set the maximum size to 0. The number entered for the minimum size desired may not be identical to the maximum size desired. If a specific sized system is desired, for example 100 kW, please enter 100 as the minimum size and a slightly larger number, such as 100.000001 as the maximum size. ***This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Back to PV System Characteristics

Module type
□ - The module type describes the photovoltaic modules in the array. If you do not have information about the modules in the system, use the default Standard module type. Otherwise, you can use the nominal module efficiency, cell material, and temperature coefficient from the module data sheet to choose the module type.

Type	*Approximate Efficiency*	*Module Cover*	*Temperature Coefficient of Power*
Standard (crystalline silicon)	*15%*	*Glass*	*-0.47 %/°C*
Premium (crystalline silicon)	*19%*	*Anti-reflective*	*-0.35 %/°C*
Thin Film	*10%*	*Glass*	*-0.20 %/°C*

REopt uses PVWatts® to model PV. PVWatts® uses a basic set of equations to represent the module's physical properties and performance. The module type determines how PVWatts® calculates the angle-of-incidence correction factor as sunlight passes through the module cover *to the photovoltaic cell, and the cell's operating temperature. (See the* Technical Reference *for details).*

Back to PV System Characteristics

Array type

 - *The array type describes whether the PV modules in the array are fixed, or whether they move to track the movement of the sun across the sky with one or two axes of rotation. Options include: Rooftop, Fixed; Ground Mount, Fixed (open rack); and Ground Mount, 1-Axis Tracking. The default value is a rooftop, fixed system. If 0 is entered in the roofspace available input field, the default changes to ground mount, fixed.*

For systems with fixed arrays, you can choose between an open rack or a roof mount option. The open rack option is appropriate for ground-mounted systems. It assumes that air flows freely around the array, helping to cool the modules and reduce cell operating temperatures. (The array's output increases as the cell temperature decreases at a given incident solar irradiance.) The roof mount option is typical of residential installations where modules are attached to the roof surface with standoffs that provide limited air flow between the module back and roof surface (typically between two and six inches).

REopt uses PVWatts to model PV. For the open rack option, PVWatts assumes an installed nominal operating temperature (INOCT) of 45 degrees Celsius. For roof mount systems, the INOCT is 50 degrees Celsius, which corresponds roughly to a three or four inch standoff height. See the Technical Reference *for details.*

Back to PV System Characteristics

Array azimuth (deg)

 - *For a fixed array, the azimuth angle is the angle clockwise from true north describing the direction that the array faces. An azimuth angle of 180° is for a south-facing array, and an azimuth angle of zero degrees is for a north-facing array.*

For an array with one-axis tracking, the azimuth angle is the angle clockwise from true north of the axis of rotation.

The default value is an azimuth angle of 180° (south-facing) for locations in the northern hemisphere. This value typically maximizes electricity production over the year, although local weather patterns may cause the optimal azimuth angle to be slightly more or less than the default values. For the northern hemisphere, increasing the azimuth angle favors afternoon energy production, and decreasing the azimuth angle favors morning energy production.

Azimuth angles for different compass headings:

Heading	***Azimuth Angle***
N	*0°*
NE	*45°*
E	*90°*

SE	*135°*
S	*180°*
SW	*225°*
W	*270°*
NW	*315°*

The maximum number entered must be less than or equal to 360—an error will display if a higher value is entered.

Back to PV System Characteristics

Array tilt (deg)

□ - The tilt angle is the angle from horizontal of the photovoltaic modules in the array. For a fixed array, the tilt angle is the angle from horizontal of the array where 0° = horizontal, and 90° = vertical. For arrays with one-axis tracking, the tilt angle is the angle from horizontal of the tracking axis.

By default, REopt sets the tilt angle to 10 degrees for a rooftop system, equal to the site's latitude for a ground mount fixed system, and to 0 degrees for a one axis tracking system. Setting the tilt equal to the latitude does not necessarily maximize the net annual output of the system, as lower tilt angles favor peak production in the summer months and higher tilt angles favor lower irradiance conditions in the winter months. Designers often use a lower tilt angle to minimize the cost of racking and mounting hardware, or to minimize the risk of wind damage to the array.

In general, using a tilt angle greater than the location's latitude favors energy production in the winter and using a tilt angle less than the location's latitude favors energy production in the summer.

For a PV array on a building's roof, you may want to choose a tilt angle equal to the roof pitch. Use the table below to convert roof pitch in ratio of rise (vertical) over run (horizontal) to tilt angle.

Photovoltaic array tilt angle for different roof pitches

Roof Pitch (rise/run)	***Tilt Angle***
4/12	*18.4°*
5/12	*22.6°*
6/12	*26.6°*
7/12	*30.3°*
8/12	*33.7°*
9/12	*36.9°*
10/12	*39.8°*
11/12	*42.5°*
12/12	*45°*

The maximum number entered must be less than or equal to 90—an error will display if a higher value is entered.

Back to PV System Characteristics

DC to AC size ratio

□ - The DC to AC size ratio is the ratio of the inverter's AC rated size to the array's DC rated size. Increasing the ratio increases the system's output over the year, but also increases the array's cost. The default value is 1.20, which means that a 4 kW system size would be for an array with a 4 DC kW nameplate size at standard test conditions (STC) and an inverter with a 4 DC kW / 1.2 = 3.33 AC kW nameplate size.

For a system with a high DC to AC size ratio, during times when the array's DC power output exceeds the inverter's rated DC input size, the inverter limits the array's power output by increasing the DC operating voltage, which moves the array's operating point down its current-voltage (I-V) curve. REopt uses PVWatts® to model PV. PVWatts® models this effect by limiting the inverter's power output to its rated AC size.

The default value of 1.20 is reasonable for most systems. A typical range is 1.10 to 1.25, although some large-scale systems have ratios of as high as 1.50. The optimal value depends on the system's location, array orientation, and module cost.

The maximum number entered must be less than or equal to 2—an error will display if a higher value is entered.

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System losses (%)

□ - REopt uses PVWatts to model PV. The system losses account for performance losses you would expect in a real system that are not explicitly calculated by the PVWatts model equations.

The default value for the system losses of 14% is based on the categories in the table below, and calculated as follows:

$100\% * (1 - (1 - 0.02) * (1 - 0.03) * (1 - 0.02) * (1 - 0.02) * (1 - 0.005) * (1 - 0.015) * (1- 0.01) * (1 - 0.03)) = 14\%$

The inverter's DC-to-AC conversion efficiency is a separate, non-adjustable input with a value of 96%. Do not include inverter conversion losses in the system loss percentage.

PVWatts® calculates temperature-related losses as a function of the cell temperature, so you should not include a temperature loss factor in the system loss percentage. See the Technical Reference for details.

Default values for the system loss categories:

Category	*Default Value (%)*

Soiling	*2*
Shading	*3*
Snow	*0*
Mismatch	*2*
Wiring	*2*
Connections	*0.5*
Light-Induced Degradation	*1.5*
Nameplate Rating	*1*
Age	*0*
Availability	*3*

The maximum number entered must be less than or equal to 99—an error will display if a higher value is entered.

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PV Incentives and Tax Treatment

Tax Treatment

MACRS schedule
- MACRS Schedule: The Modified Accelerated Cost Recovery System (MACRS) is the current tax depreciation system in the United States. Under this system, the capitalized cost (basis) of tangible property is recovered over a specified life by annual deductions for depreciation. The user may specify the duration over which accelerated depreciation will occur (0, 5, or 7 years). Additional information is available here*.*

When claiming the ITC, the MACRS depreciation basis is reduced by half of the value of the ITC.

The default is set to 5 years. Note that there is an option in the right margin of the PV section to “Reset to default values.” See REopt Lite Web Tool Default Values for information on default values.

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Battery Inputs

Allow grid to charge battery?
--- Advanced inputs
Battery Costs
Battery Characteristics
Battery Incentives and Tax Treatment

Back to Data Inputs

Energy capacity cost ($/kWh)

□ - Energy capacity cost is the cost of the energy components of the battery system (e.g. battery pack).

The amount of energy that a battery can store is determined by its capacity [kWh] while the rate at which it charges or discharges is determined by its power rating [kW]. While PV system cost is typically estimated based on power rating [kW] alone, ***battery costs are estimated based on both capacity [kWh] and power [kW]****.*

The power components of the system (e.g., inverter, balance of system [BOS]) are captured by the power metric of $/kW and the energy components of the system (e.g., battery) are captured by the energy metric of $/kWh.

This allows the capacity (kWh) and power (kW) rating of the battery to be optimized individually for maximum economic performance based on the load and rate tariff characteristics of the site. Some systems are optimized to deliver high power capacity (kW), while others are optimized for longer discharges through more energy capacity (kWh).

For example, assume the unit cost of power components is $1,000/kW, and the unit cost of energy components is $500/kWh. Consider a battery with 5 kW of power capacity and 10 kWh of energy capacity (5 kW/10 kWh). The total cost of the battery would be:

*(5 kW * $1,000/kW) + (10 kWh * $500/kWh) = $10,000*

The maximum number entered must be less than or equal to 10,000—an error will display if a higher value is entered.

This is a key driver input.

Back to Battery Inputs

Power capacity cost ($/kW)

□ - Power capacity cost is the cost of the power components of the battery system (e.g. inverter and balance of system [BOS]).

*The amount of energy that a battery can store is determined by its capacity [kWh] while the rate at which it charges or discharges is determined by its power rating [kW]. While PV system cost is typically estimated based on power rating [kW] alone, **battery costs are estimated based on both capacity [kWh] and power [kW]**.*

The power components of the system (e.g., inverter, balance of system [BOS]) are captured by the power metric of $/kW and the energy components of the system (e.g., battery) are captured by the energy metric of $/kWh.

This allows the capacity (kWh) and power (kW) rating of the battery to be optimized individually for maximum economic performance based on the load and rate tariff characteristics of the site. Some systems are optimized to deliver high power capacity (kW), while others are optimized for longer discharges through more energy capacity (kWh).

For example, assume the unit cost of power components is $1,000/kW, and the unit cost of energy components is $500/kWh. Consider a battery with 5 kW of power capacity and 10 kWh of energy capacity (5 kW/10 kWh). The total cost of the battery would be:

*(5 kW * $1,000/kW) + (10 kWh * $500/kWh) = $10,000.*

The maximum number entered must be less than or equal to 10,000—an error will display if a higher value is entered.

This is a key driver input.

Back to Battery Inputs

Allow grid to charge battery?

* - If this input is set to no, the grid cannot charge the battery. Only the renewable energy system will charge the battery. If it is set to yes, either the grid or the renewable energy system can charge the battery. The default is set to yes in order to allow evaluation of batteries that are not connected to a renewable energy system.*
Whether or not the grid charges the battery impacts the owner's ability to take advantage of the federal investment tax credit (ITC) and Modified Accelerated Depreciation (MACRS). See Battery Incentives and Tax Treatment section for more information.

This is a key driver input.

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--- Advanced inputs

Battery Costs

Energy capacity replacement cost
Energy capacity replacement year
Power capacity replacement cost
Power capacity replacement year

Energy capacity replacement cost ($/kWh)
□ - Energy capacity replacement cost is the expected cost, in today's dollars, of replacing the energy components of the battery system (e.g. battery pack) during the project lifecycle. ***This value is not required.***

The maximum number entered must be less than or equal to 10,000—an error will display if a higher value is entered.

Energy capacity replacement year
□ - Energy capacity replacement year is the year in which the energy components of the battery system (e.g. battery pack) are replaced during the project lifecycle. The default is year 10. ***This value is not required.***

Power capacity replacement cost ($/kW)
□ - Power capacity replacement cost is the expected cost, in today's dollars, of replacing the power components of the battery system (e.g. inverter, balance of systems) during the project lifecycle. ***This value is not required.***

The maximum number entered must be less than or equal to 10,000—an error will display if a higher value is entered.

Power capacity replacement year
□ - Power capacity replacement year is the year in which the power components of the battery system (e.g. inverter, balance of systems) are replaced during the project lifecycle. The default is year 10. ***This value is not required.***

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Battery Characteristics

Energy Capacity
Power Capacity
Efficiency
State of Charge

Minimum energy capacity (kWh)
□ - REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The minimum energy capacity size forces a battery energy capacity of at least this size to appear at a site. The default value is 0 (no minimum size). The number entered for the minimum size desired may not be identical to the maximum size desired. If a specific sized system is desired, for

example 100 kWh, please enter 100 as the minimum size and a slightly larger number, such as 100.000001 as the maximum size. ***This value is not required.***

Maximum energy capacity (kWh)
□ - REopt identifies the system size that minimizes the life cycle cost of energy at the site. The maximum energy capacity size limits the battery energy capacity to no greater than the specified maximum. To remove a technology from consideration in the analysis, set the maximum size to 0. The default value is 1,000,000 kWh. The number entered for the minimum size desired may not be identical to the maximum size desired. If a specific sized system is desired, for example 100 kWh, please enter 100 as the minimum size and a slightly larger number, such as 100.000001 as the maximum size. ***This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Back to Battery Inputs

Minimum power capacity (kW)
□ - REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The minimum power capacity size forces a battery power capacity of at least this size to appear at a site. The default value is 0 (no minimum size). The number entered for the minimum size desired may not be identical to the maximum size desired. If a specific sized system is desired, for example 100 kW, please enter 100 as the minimum size and a slightly larger number, such as 100.000001 as the maximum size. ***This value is not required.***

Maximum power capacity (kW)
□ - REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The maximum power capacity size limits the battery power capacity to no greater than the specified maximum. The default value is 1,000,000 kW. The number entered for the minimum size desired may not be identical to the maximum size desired. If a specific sized system is desired, for example 100 kW, please enter 100 as the minimum size and a slightly larger number, such as 100.000001 as the maximum size. ***This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

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Rectifier efficiency (%)
□ - The rectifier's nominal rated AC-to-DC conversion efficiency, defined as the rectifier's rated DC power output divided by its rated AC power output. The default value is 96%. ***This value is not required.***

Round trip efficiency (%)
□ - This is the ratio of the DC power put into a battery to the DC power retrieved from the same battery. The default value is 97.5%. ***This value is not required.***

Inverter efficiency (%)

□ - The inverter's nominal rated DC-to-AC conversion efficiency, defined as the inverter's rated AC power output divided by its rated DC power output. The default value is 96%. ***This value is not required.***

Total AC-AC round trip efficiency

□ - The ratio of the AC power put into a battery to the AC power retrieved from the same battery. Note that the round trip efficiency only accounts for DC power in and out of the battery, while the total AC-AC round trip efficiency also accounts for the need to convert AC power to DC in order to charge the battery, and DC power to AC in order to discharge the battery. This is equal to the product of the round trip efficiency, the inverter efficiency, and the rectifier efficiency. The default value is 89.9%.

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Minimum state of charge (%)

□ - The lowest desired level of charge of the battery. For lithium-ion batteries, this is typically 20%. ***This value is not required.***

Initial state of charge (%)

□ - This is the initial state of charge of the battery at the beginning of the analysis period. The default is 50%. ***This value is not required.***

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Battery Incentives and Tax Treatment

Capital Cost Based Incentives

□ - Federal, State, and Utility capital tax credits and incentives can be entered in this section. Each incentive can either be entered as a percentage of capital cost or as a rebate per kW.

Total percentage-based incentive (%)

□ - Incentives given as a percentage of capital costs. The percentage-based incentive is treated as a tax-based incentive to model the federal investment tax credit. Note that whether or not the grid charges the battery impacts the owner's ability to take advantage of the federal investment tax credit (ITC).

The default for percentage-based incentives is $0, corresponding to the default of the battery charging from the grid. New Tax laws concerning battery systems are pending. Please consult current rules. The 2020 Federal 26% investment tax credit is generally understood to be available to batteries charged 100% by eligible RE technologies, including solar and wind, when they are installed as part of a renewable energy system. Batteries charged by a RE system 75%-99% of the time are eligible for that portion of the ITC. For example, a system charged by RE 80% of the time is eligible for the 26% ITC multiplied by 80%, which equals a 20.8% ITC *instead of 26%. Look up additional incentives at* www.dsireusa.org*. Refer to the IRS for the latest regulations.*

Units: decimal percent. ***This value is not required.***

The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

Total rebate ($/kW)
 - Rebates offered based on installed system size. ***This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

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Tax Treatment

MACRS schedule
 - The modified Accelerated Cost Recovery System (MACRS) is the current tax depreciation system in the United States. Under this system, the capitalized cost (basis) of tangible property is recovered over a specified life by annual deductions for depreciation. The user may specify the duration over which accelerated depreciation will occur (0, 5, or 7 years). Additional information is available here*.*

Note that whether or not the grid charges the battery impacts the owner's ability to take advantage of the federal investment tax credit (ITC) and Modified Accelerated Depreciation (MACRS).

Without a renewable energy system installed, battery systems are eligible for the 7-year MACRS depreciation schedule: an equivalent reduction in capital cost of about 20% (assuming a 26% federal tax rate and an 8% discount rate). The same benefit applies to battery systems installed along with a renewable energy system if the battery is charged by the renewable energy system less than 75% of the time. If the battery system is charged by the renewable energy system more than 75% of the time on an annual basis, the battery should qualify for the 5-year MACRS schedule, equal to about a 21% reduction in capital costs.

When claiming the ITC, the MACRS depreciation basis is reduced by half of the value of the ITC. Refer to the IRS for the latest regulations.

The default is set to 7 years. Note that there is an option in the right margin of the Battery section to "Reset to default values." See REopt Lite Web Tool Default Values for information on default values.

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Wind Inputs

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Size class:

□ - The wind size class selected will determine the potential wind energy production for the site location. The size class should be selected based on site load and wind resource.

The size class label refers only to the turbine size, as determined by the rated capacity (or system size), and not the end-use sector. For example, residential sized turbines are often used in commercial applications.

Large (>=1000 kW)
Midsize (101-999 kW)
Commercial (21-100 kW)
Residential (0-20 kW)

The chart below gives the representative turbine sizes used by REopt Lite for each wind size class. ***For the optimization, a single turbine installation is generally assumed****.*

Wind Size Class Representative Sizes			
Size Class	System Size	Hub Height	Rotor
-	(kW)	Height (m)	Radius (m)
Residential	2.5	20	1.85
Commercial	100	40	13.8
Midsize	250	50	21.9
Large	2,000	80	55

Assessing the Future of Distributed Wind: Opportunities for Behind-the-Meter Projects. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-67337.

REopt Lite uses the site location and the wind size class selected to access wind resource data from the Wind Integration National Dataset (WIND) Toolkit. The WIND Toolkit includes meteorological conditions and turbine power for more than 126,000 sites in the continental United States for the years 2007–2013. REopt Lite uses 2012 data because it is close to the WIND Toolkit overall average wind generation across 2007-2013

(Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit)

The Wind Toolkit provides wind speed, air pressure, air temperature, and wind direction at an hourly resolution. These values returned by the WIND Toolkit, together with wind turbine power curves for the representative turbine sizes, are processed by the System Advisor Model (SAM) to produce the wind energy generation values used for the optimization (https://sam.nrel.gov).

The representative power curves were developed as part of the dWind effort described in Assessing the Future of Distributed Wind: Opportunities for Behind-the-Meter Projects, but assume near future turbine technology advancements described in this source:

	Residential (2.5kW)	**Commercial (100kW)**	**Midsize (250kW)**	**Large (2000kW)**
Wind Speed (m/s)	**kW**	**kW**	**kW**	**kW**
2	0	0	0	0
3	0.070542773	3.50595	8.764875	70.119
4	0.1672125	8.3104	20.776	166.208
5	0.326586914	16.23125	40.578125	324.625
6	0.564342188	28.0476	70.119	560.952
7	0.896154492	44.53855	111.346375	890.771
8	1.3377	66.4832	166.208	1329.664
9	1.904654883	94.66065	236.651625	1893.213
10	2.5	100	250	2000

If no wind size class is selected, the default wind class value of 'commercial' will be used. However, the selection of a size class doesn't limit the minimum and maximum sizes considered in the optimization to that range, and if the results recommend a wind turbine in a different size class than that selected, the results will be flagged and the user can iterate on the analysis inputs, updating the size class and re-running the optimization. This value is not required.

Note: Depending on the wind resource and financial inputs for the site location, the optimization may recommend a wind capacity that is outside of the range of sizes defined by the size class that was selected for the optimization. In this case, the production and cost data may have been used to get the result, because wind energy production varies with Rotor Radius and Hub Height and the default cost is also dependent on the wind size class chosen.

Example: the user selects large class size (>1000 kW), but gets a recommendation of 54 kW wind. This means that the recommended 54 kW turbine was incorrectly costed at the cheaper large-class cost and its production estimate used the superior wind resource of a taller large-class turbine.

If this situations occurs, the user receives red warning text immediately below the recommended wind size in the top box on the results page.

*** The recommended wind size is outside the range of turbine sizes in the Wind Size Class that was used in the optimization. Please edit inputs to select the Wind Size Class that is consistent with this result.**

If this warning is given, please return to the input page and chose the Wind Size Class that corresponds to the recommended wind system capacity and re-run the optimization. If the new cost is significantly higher than the original cost, the optimization may recommend a smaller turbine, or no turbine.

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Wind System capital cost ($/kW)

□ - Fully burdened cost of installed wind system in dollars per kilowatt. The chart below gives the default system capital costs that are used by REopt Lite for each wind size class. If a custom cost is entered, it will be used instead of the default cost. ***This value is not required.***

Wind CAPEX Defaults				
Size Class	*System Size*	*Base Cost*	*Hub Height*	*Rotor*
-	*(kW)*	*($/kW)*	*Height (m)*	*Radius (m)*
Residential	*2.5*	*$11,950*	*20*	*1.85*
Commercial	*100*	*$7,390*	*40*	*13.8*
Midsize	*250*	*$4,440*	*50*	*21.9*
Large	*2,000*	*$3,450*	*80*	*55*

The maximum number entered must be less than or equal to $100,000/kW—an error will display if a higher value is entered.

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Wind Capital Cost Based Incentives

□ - Federal, State, and Utility capital tax credits and incentives can be entered in this table. Each incentive can either be entered as a percentage of capital cost, with a maximum dollar amount, or as a rebate per kW, with a maximum dollar amount. Incentives are considered in the following order; utility, state, then federal. For example, if there is a 20% utility incentive and a 30% state incentive, the 20% utility incentive would be applied first, then the 30% state incentive would be applied to the reduced cost. The incentives are not additive, that is, the site would not get a 20% + 30% = 50% discount. The default value for federal capital cost based incentive is the business energy investment tax credit. Look up additional incentives at www.dsireusa.org.

Wind Percentage-based incentive (%)

□ - Incentives given as a percentage of capital costs. The federal percentage-based incentive is treated as a tax-based incentive to model the federal investment tax credit. All other incentives are not tax-based. Units: decimal percent. ***This value is not required.***

The default for Federal Percentage-based Incentive (Investment Tax Credit or ITC) changes depending on whether the system capacity chosen is above or below100 kW, and thus classified as Small Wind or Large Wind. More information here. The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

Wind Maximum incentive ($)

□ - The maximum dollar value of the percentage based incentives. If there is not a maximum, the value defaults to 'Unlimited'. ***This value is not required.***

A maximum incentive amount can be specified for State and Utility incentives. The federal incentive maximum is set as unlimited. The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Wind Rebate ($/kW)

□ - Rebates offered based on installed system size. ***This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Wind Maximum rebate ($)

□ - The maximum dollar value of the rebate, if there is not a maximum, the value defaults to 'Unlimited'. ***This value is not required.***

A maximum rebate amount can be specified for State and Utility level incentives. The federal incentive maximum is set as unlimited. The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

The incentives are key driver inputs.

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Wind Production Based Incentives

□ - Federal, State, and Utility production incentives can be entered here. If there is more than one production based incentive offered, the combined value can be entered and should be discounted back to year one if the incentive duration differs. Look up incentives at www.dsireusa.org.

Wind Production incentive ($/kWh)

□ - The dollar value of the incentive per kWh produced. ***This value is not required.***

The maximum number entered must be less than or equal to 100—an error will display if a higher value is entered.

Wind Incentive duration (yrs)

□ - The number of years the production incentive is awarded. ***This value is not required.***

Wind Maximum incentive ($)

 *- The maximum incentive amount awarded each year; if there is no limit, the value defaults to 'Unlimited'. **This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Wind System size limit (kW)

 *- The maximum system size eligible for the production based incentive; if there is no limit, the value defaults to 'Unlimited'. **This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

The incentives are key driver inputs.

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--- Advanced inputs

Wind Costs

Wind O&M cost ($/kW/yr)

 *- Estimated annual wind operation and maintenance (O&M) costs per installed kilowatt. O&M includes asset cleaning, administration costs, and replacing broken components. It also includes the cost of inverter replacement. **This value is not required.***

The maximum number entered must be less than or equal to 1,000—an error will display if a higher value is entered.

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Wind System Characteristics

Minimum size desired (kW AC)

 *- REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The minimum system size forces a system of at least this size to appear at the site. If there is not enough land available, or if the interconnection limit will not accommodate the system size, the problem will be infeasible. The default value is 0 (no minimum size). The number entered for the minimum size desired may not be identical to the maximum size desired. If a specific sized system is desired, for example 100 kW, please enter 100 as the minimum size and a slightly larger number, such as 100.000001 as the maximum size. **This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

Maximum size desired (kW AC)

□ - REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The maximum size limits the wind system to no greater than the specified maximum. To remove a technology from consideration in the analysis, set the maximum size to 0. The number entered for the minimum size desired may not be identical to the maximum size desired. If a specific sized system is desired, for example 100 kW, please enter 100 as the minimum size and a slightly larger number, such as 100.000001 kW as the maximum size. ***This value is not required.***

The maximum number entered must be less than or equal to 1,000,000,000—an error will display if a higher value is entered.

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Wind Incentives and Tax Treatment

MACRS schedule:

□ - MACRS Schedule: The Modified Accelerated Cost Recovery System (MACRS) is the current tax depreciation system in the United States. Under this system, the capitalized cost (basis) of tangible property is recovered over a specified life by annual deductions for depreciation. The user may specify the duration over which accelerated depreciation will occur (0, 5, or 7 years). Additional information is available here.

When claiming the ITC, the MACRS depreciation basis is reduced by half of the value of the ITC.

The default is set to 5 years. Note that there is an option in the right margin of the Wind section to “Reset to default values.” See REopt Lite Web Tool Default Values for information on default values.

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Generator Inputs

Fuel burn rate for diesel generator
Fuel consumption curve y-intercept for diesel generator

Generator Installed cost ($/kW)

*□ - Fully burdened cost of the new installed generator in dollars per kilowatt. **This value is not required.***

Diesel cost ($/gal)

*□ - Fully burdened cost of diesel fuel in dollars per gallon. **This value is not required.***

Fuel availability (gallons)

*□ - If the Existing diesel generator option is selected, then the amount of fuel that is available for the existing generator is **required** to complete the optimization for energy resilience.*

Existing diesel generator checkbox

This checkbox allows the user to consider an existing Generator in the Resilience optimization.

Existing diesel generator size (kW)
*□ - If the Existing diesel generator option is selected, then the size of the existing generator is **required** to complete the optimization for energy resilience.*

If the site has an existing generator, enter its size in kW. The existing generator will be factored into Business as Usual O&M cost calculations and net-metering credits and limits.

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--- Advanced inputs

Generator Costs

Fixed O&M cost ($/kW)
*□ - Estimated annual generator operation and maintenance (O&M) costs per installed kilowatt (including both new and existing generators). Includes regular O&M based on calendar intervals including testing, stored fuel maintenance, and service contracts. **This value is not required.***

Variable O&M cost ($/kWh)
*□ - Estimated non-fuel operation and maintenance (O&M) costs which vary with the amount of electricity produced (by both new and existing generators). Variable O&M may include filters and oil changes, and other maintenance requirements based on engine run-hours. **This value is not required.***

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Generator Characteristics

Minimum new generator size (kW)
 - *REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The minimum new generator size forces a new generator of at least this size to appear at the site. The default value is 0 (no minimum size). If a specific sized new generator is desired, please enter that size as both the minimum size and also the maximum size.* ***This value is not required.***

Maximum new generator size (kW)
 - *REopt identifies the system size that minimizes the lifecycle cost of energy at the site. The maximum new generator size limits the new generator size to no greater than the specified maximum. To remove a technology from consideration in the analysis, set the maximum size to 0. The default value is 1,000,000,000 kW. If a specific sized new generator is desired, please enter that size as both the minimum size and also the maximum size.* ***This value is not required.***

Fuel burn rate for diesel generator (gallons/kWh)
 - *If a fuel burn rate for the diesel generator is not entered by the user, then a default burn rate will be used.*

Fuel consumption curve y-intercept for diesel generator (gallons/hour)
 - *The fuel curve intercept is equivalent to the no-load fuel consumption of the generator. If a fuel curve intercept is not entered by the user, then a default fuel curve intercept of zero will be used.*

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REopt Lite Web Tool Results

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Results for Your Site

The key results from the REopt Lite Web Tool are summarized in this section. The Back button returns the user to the input page to edit the inputs and alter the scenario for a new evaluation in cases where the evaluation has just been completed. If the user opened the results page from the Saved Evaluations dashboard, then the Back button will return the user to the dashboard. To return to edit inputs for a previous scenario accessed from the dashboard, choose Copy from the dashboard.

Your recommended solar installation size

Measured in kW of direct current, this recommended size minimizes the life cycle cost of energy at the site, given the set of inputs used in the analysis. This optimized size may not be commercially available. The user is responsible for finding a commercial product that is closest in size to this optimized size. The total system PV size includes an existing PV system if one has been specified in the inputs.

PV is typically recommended if it reduces the life cycle cost of energy for the site. PV is often cost-effective at sites that have a higher utility energy rate, higher utility escalation rate, lower PV cost, good incentives, and/or good solar resource that make energy generated by PV less expensive than energy purchased from the utility. If PV is not recommended, it may not be cost-effective at this site.

If the user specified a minimum PV size or a resiliency requirement, PV may be recommended to meet these requirements even if it does not reduce the life cycle cost of energy. If the user specified only wind and/or battery and/or generator analysis or set a maximum PV size of 0, PV will not be recommended even if it is cost-effective.

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Your recommended wind installation size

Measured in kW of alternating current, this recommended size minimizes the life cycle cost of energy at the site, given the set of inputs used in the analysis. This optimized size may not be commercially available. The user is responsible for finding a commercial product that is closest in size to this optimized size.

Wind is typically recommended if it reduces the life cycle cost of energy for the site. Wind is often cost-effective at sites that have a higher utility energy rate, higher utility escalation rate, lower wind cost, good incentives, and/or good wind resources that make energy generated by wind less expensive than energy purchased from the utility. If wind is not recommended, it may not be cost-effective at this site.

If the user specified a minimum wind size or a resiliency requirement, wind may be recommended to meet these requirements even if it does not reduce the life cycle cost of energy.

If the user specified only PV and/or battery and/or generator analysis or set a maximum wind size of 0, wind will not be recommended even if it is cost-effective.

Note: Depending on the wind resource and financial inputs for the site location, the optimization may recommend a wind capacity that is outside of the range of sizes defined by the size class that was selected for the optimization. In this case, the production and cost data may have been used to get the result, because wind energy production varies with Rotor Radius and Hub Height and the default cost is also dependent on the wind size class chosen.

Example: the user selects large class size (>1000 kW), but gets a recommendation of 54 kW wind. This means that the recommended 54 kW turbine was incorrectly costed at the cheaper large-class cost and its production estimate used the superior wind resource of a taller large-class turbine.

If this situations occurs, the user receives red warning text immediately below the recommended wind size in the top box on the results page.
*** The recommended wind size is outside the range of turbine sizes in the Wind Size Class that was used in the optimization. Please edit inputs to select the Wind Size Class that is consistent with this result. NOTE: if the new Wind Size Class that corresponds to this recommended wind size has a higher cost than the original cost, the new optimization may recommend a smaller turbine, or no turbine.**
If this warning is given, please return to the input page and chose the Wind Size Class that corresponds to the recommended wind system capacity and re-run the optimization. If the new cost is significantly higher than the original cost, the optimization may recommend a smaller turbine, or no turbine.

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Your recommended battery power and capacity

This battery system size minimizes the life cycle cost of energy at the site, given the set of inputs used in the analysis. The battery power (kW-AC) and capacity (kWh) are independently optimized for economic performance (and resiliency, if resiliency requirements are specified)—a power:energy ratio is not predefined. This optimized size may not be commercially available. The user is responsible for finding a commercial product that is closest in size to this optimized size.

A battery is typically recommended if it reduces the life cycle cost of energy for the site. A battery is often cost-effective at sites that have a higher utility demand rates or time-of-use rates, higher utility escalation rate, lower battery cost, and/or good battery incentives. The battery is used for peak shaving and energy arbitrage to reduce utility costs. If a battery is not recommended, it may not be cost-effective at this site.

If the user specified a minimum battery size or a resiliency requirement, a battery may be recommended to meet these requirements even if it does not reduce the life cycle cost of energy.

If the user specified only PV and/or wind and/or generator or set a maximum battery size of 0, a battery will not be recommended even if it is cost-effective.

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Your recommended generator size

This generator size minimizes the life cycle cost of energy at your site during a grid outage. The generator size is measured in kilowatts (kW) of alternating current (AC). This optimized size may not be commercially available. The user is responsible for finding a commercial product that is closest in size to this optimized size. The total system generator size includes an existing generator if one has been specified in the inputs.

A generator is typically recommended if it reduces the life cycle cost of energy for the site to meet a critical load during an electricity outage. If a generator is not recommended, it may not be cost-effective at this site.

If you specified a minimum generator size or a resiliency requirement, a generator may be recommended to meet these requirements even if it does not reduce the life cycle cost of energy. If you specified only PV and/or wind and/or battery analysis or set a maximum generator size of 0, a generator will not be recommended even if it is cost-effective.

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Your potential life cycle savings (analysis period)

This is the net present value of the savings (or costs if negative) realized by the project based on the difference between the life cycle energy cost of doing business as usual compared to the optimal case.

If the user specified a minimum PV, wind, or battery size or a resiliency requirement, the net present value may be negative.

Your Potential Resilience

This section of results is displayed for a resilience evaluation and confirms that the recommended system sustains the critical load specified for the outage period specified and displays the details of this specified outage.

The section also displays the percentage of outages, of the same duration and load, which the recommended system would sustain out of all potential outage start hours through the entire year. More detail on outage survival is provided by opening the Outage Simulation option displayed in the Resilience vs. Financial section of the results.

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System Performance Year One Graph

This is an interactive graph of the dispatch strategy optimized by the REopt Lite Web Tool. Click to select a date, then drag right to zoom in on a date range. Click anywhere on the graph and drag left to zoom out in proportion to the distance moved on the graph. Click the Reset Zoom button to return to the graph of data for a full year.

For every hour of the year, the chart shows the electric load in a solid black line. The load must be met in each hour by either energy purchased from the grid, PV, wind, or battery. The PV and wind generate energy according to when the resource is available, and either serve the load, charge the battery, or export to the grid. Load not met by PV and/or wind is met either by the battery discharging or by the grid.

The optimization model decides whether to charge, discharge, or do nothing with the battery in each hour. If it charges or discharges it also decides by how much. The battery state of charge is shown as a dotted black line. If a diesel generator has been entered, its serving load is also represented on the graph. The battery is sized and dispatched to minimize the life cycle cost of energy at the site. There is no demand target; instead, the optimization model determines demand levels.

There is an option to download a Dispatch Spreadsheet, as a .csv file, by clicking the link below the System Performance Graph.

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Resilience vs. Financial

Resilience vs. Financial Benefits Chart

This chart is included in the Result when a Resilience Optimization has been selected. It compares the results for an optimization for Resilience to a Financial optimization and to a business as usual system for the high level values of PV Size, Wind Size, Battery Power and Capacity, Net Present Value, Average Resiliency, Minimum Resiliency, Maximum Resiliency, and Diesel Generator Fuel Used. The resiliency results show how the system performs during outages occurring at other times of the year. Outages are simulated starting at every hour of the year and the amount of time the system can sustain the critical load during each outage is calculated.

Business as Usual Case

□ - In this case, the NPV refers to the situation where the site purchases energy solely from the utility. In a scenario modeling a grid outage where the critical load can be fully met by an existing generator for some period of time, then Business As Usual also refers to the costs of using that existing generation capacity for that time. Outage stats are from the outage simulation, including existing diesel if specified by user.

Resilience Case

□ - The case that minimizes the present value of all future energy costs over the analysis period. This case may include a combination of utility, PV, wind, battery, and/or diesel generator. This case is optimized to sustain a critical load in the event of a grid outage.

Financial Case

□ - The case that minimizes the present value of all future energy costs over the analysis period. This case may include a combination of utility, PV, wind, and/or battery. This case is not optimized for a grid outage.

System

□ - The recommended sizes for recommended system components: Diesel Generator size in kW-AC, PV size in kW-DC, Wind size in kW-AC, Battery Power size in kW-AC, Battery Capacity size in kWh. These system sizes minimize the lifecycle cost of energy at the site, given the set of inputs used in this analysis.

NPV

□ - The present value of the savings (or costs if negative) realized by the project. This is calculated as the difference between the "Business As Usual" case lifecycle energy cost and the "Resilience Case" life cycle energy cost or the "Financial Case" life cycle energy cost.

Survives Specified Outage

□ - Determination of whether the system, as defined by its particular inputs, will sustain the critical load specified by the resilience case inputs during the outage period specified by the resilience case inputs.

Average Resiliency (hours)

□ - The average amount of time that the system can sustain the critical load. 8,760 outage simulations are run - one for each hour of the year - and the Average Resiliency is calculated as the average time survived during the simulated outages.

The battery state of charge at the start of each outage is determined by the economically optimal dispatch strategy. This means that if the battery was being used for peak shaving prior to the outage, it may be at a low state of charge when the outage occurs.

Note that in order to gain this resiliency, the PV/wind/battery/generator must be installed as an island-able system. This incurs additional costs above a typical grid-connected system that are not included in the economics presented here. Additional components required may include a manual or automatic transfer switch, critical load panel, and additional controls capabilities in the inverter for islanded operation.

Minimum Resiliency (hours)

□ - The minimum amount of time that the system can sustain the critical load. 8,760 outage simulations are run - one for each hour of the year - and the Minimum Resiliency is calculated as the minimum time survived during the simulated outages.

The battery state of charge at the start of each outage is determined by the economically optimal dispatch strategy. This means that if the battery was being used for peak shaving prior to the outage, it may be at a low state of charge when the outage occurs.

Note that in order to gain this resiliency, the PV/wind/battery/generator must be installed as an island-able system. This incurs additional costs above a typical grid-connected system that are not included in the economics presented here. Additional components required may include a manual or automatic transfer switch, critical load panel, and additional controls capabilities in the inverter for islanded operation.

Maximum Resiliency (hours)

□ - The maximum amount of time that the system can sustain the critical load. 8,760 outage simulations are run - one for each hour of the year - and the Maximum Resiliency is calculated as the maximum time survived during the simulated outages.

The battery state of charge at the start of each outage is determined by the economically optimal dispatch strategy. This means that if the battery was being used for peak shaving prior to the outage, it may be at a low state of charge when the outage occurs.

Note that in order to gain this resiliency, the PV/wind/battery/generator must be installed as an island-able system. This incurs additional costs above a typical grid-connected system that are not included in the economics presented here. Additional components required may include a manual or automatic transfer switch, critical load panel, and additional controls capabilities in the inverter for islanded operation.

Diesel Generator Fuel Used (gallons)

□ - Generator fuel used to meet critical load during grid outage for optimized economic performance. The total fuel used is dependent on the size of the generator(s) as specified in the inputs for Fuel burn rate and Fuel consumption curve y-intercept.

This result is displayed when a generator has been selected as a technology for a resilience evaluation.

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Outage Simulation

Selecting the Simulate Outages button will provide an evaluation of the amount of time that your system can survive grid outages. Data can be viewed for the entire year, or by month or hour. If a specific outage start time, required outage duration, and critical load factor were entered on the inputs page, the PV and/or wind plus battery will be sized to meet these requirements. Note that because load and solar and wind resource vary throughout the year, a system sized to sustain a given outage duration at one time may not be able to sustain the same outage duration occurring at a different time. The results in this simulation show how the system performs during outages occurring at other times of the year. Outages are simulated starting at every hour of the year and amount of time the system can sustain the critical load during each outage is calculated. The resilient system is compared to the business as usual system and a system designed for maximum financial benefits.

Yearly

This graph shows the amount of time the recommended system will sustain the specified critical load for outages of varying duration starting at every hour of the year. Data can be viewed for all cases or separately for each case by clicking on the keys below the graph.

Monthly

This graph shows the amount of time the recommended system will sustain the specified critical load for outages of varying duration, grouped by the month in which the outage starts. Data can be viewed for all months, or for just specified months and/or cases by clicking on the keys below the graph.

Hourly

This graph shows the amount of time the recommended system will sustain the specified critical load for outages of varying duration, grouped by the hour of the day in which the outage starts. Data can be viewed for all hours of the day, or for just specified hours and/or cases by clicking on the keys below the graph.

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Results Comparison

For a Financial Evaluation, these results show how doing business as usual compares to the optimal financial case.

Business as Usual

□ - The case where the site purchases energy solely from the utility. In a scenario modeling a grid outage where the critical load can be fully met by an existing generator, then Business As Usual also refers to the use of that existing generation capacity.

Financial Case

□ - The case that minimizes the present value of all future energy costs over the analysis period. This case may include a combination of utility, PV, wind, and/or battery. This case is not optimized for a grid outage.

Difference

□ - The difference between the optimal case and the business as usual case.

For a Resilience Evaluation, these results show how doing business as usual compares to the optimal resilience case and also to the financial case.

Business as Usual

- The case where the site purchases energy solely from the utility. In a scenario modeling a grid outage where the critical load can be fully met by an existing generator, then Business As Usual also refers to the use of that existing generation capacity.

Resilience Case
- The case that minimizes the present value of all future energy costs over the analysis period. This case may include a combination of utility, PV, wind, battery, and/or diesel generator. This case is optimized to sustain a critical load in the event of a grid outage.

Financial Case
- The case that minimizes the present value of all future energy costs over the analysis period. This case may include a combination of utility, PV, wind, and/or battery. This case is not optimized for a grid outage.

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System Size, Energy Production, and System Cost

PV Size
- The recommended PV size in kW-DC. This system size minimizes the lifecycle cost of energy at the site, given the set of inputs used in this analysis.

Annualized PV Energy Production

□ - The expected annual AC energy production from the PV system, in kWh. This is the average expected production over the system lifetime (including degradation), not year 1 production. Note PV system performance predictions are calculated by PVWatts® and include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules.

Wind Size:
□ - The recommended wind size in kW-AC. This system size minimizes the lifecycle cost of energy at the site, given the set of inputs used in this analysis.

Annualized Wind Energy Production:
□ - The expected annual AC energy production from the wind system, in kWh. This is the average expected production over the system lifetime (including degradation), not year 1 production. Note that wind performance predictions are approximate only. Actual wind turbine performance is greatly affected by obstacles surrounding the turbine, including trees, buildings, silos, fences, or any other objects that could block the wind flow. Looking at an energy rose for the site is the best way to estimate the impact of local terrain and obstacles on the potential turbine energy production.

Battery Power
□ - The recommended battery power capacity in kW. This system size minimizes the lifecycle cost of energy at the site, given the set of inputs used in this analysis. Note that the battery power and battery capacity are each optimized for maximum economic performance. The power:energy ratio is not predetermined.

Battery Capacity
□ - The recommended battery energy storage capacity in kWh. This system size minimizes the lifecycle cost of energy at the site, given the set of inputs used in this analysis. Note that the battery power and battery capacity are each optimized for maximum economic performance. The power:energy ratio is not predetermined.

Generator Size
□ - The recommended generator size in kW-AC. For the Optimal Case, this size is the total generator size recommended. If there is an existing generator, the capacity of that existing generator is included in this total. This system size minimizes the lifecycle cost of energy at the site during a grid outage, given the set of inputs used in this analysis. The generator's minimum turn down percent is set to 0 to enable it to operate at the full range of capacity (0-100%) during an outage.

Net CAPEX + Replacement + O&M
□ - The installed system cost, including the capital cost of the system (after tax and incentives) and the present value of future operation and maintenance costs for the recommended new system and for any existing PV and/or generator. If a generator is included, this line includes any fuel or variable O&M costs.

Energy Supplied From Grid in Year 1

□ - Expected energy supplied by the utility grid in year 1, in kWh.

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Year 1 Utility Cost – Before Tax

Utility Energy Cost
□ - Payments made to the utility for energy charges in year 1. This includes all charges billed in units of $/kWh.

Utility Demand Cost
□ - Payments made to the utility for demand charges in year 1. This includes all charges billed in units of $/kW.

Utility Fixed Cost
□ - Payments made to the utility for fixed charges in year 1. This includes all fixed charges on monthly and annual bases.

Utility Minimum Cost Adder
□ - These costs are added to all other utility costs in order to meet the utility's minimum charge requirements on a monthly or annual basis.

REopt Lite constrains the annual sales to the overall annual load on a kWh basis. In other words, the site gets paid (with or without net-metering) by selling energy at the "wholesale" rate, for less than or equal to the site-load. The "utility minimum cost adder" has been put in place to account for a situation where the utility rates chosen might have otherwise allowed the site to make a profit in energy sales.

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Life Cycle Utility Cost – After Tax

Utility Energy Cost
□ - Expected lifecycle cost of energy payments (all charges billed in units of $/kWh) to the utility over the analysis period, in dollars. Costs are escalated at the specified utility cost escalation rate, and then discounted back to the present using the specified discount rate.

Utility Demand Cost
□ - Expected lifecycle cost of demand payments (all charges billed in units of $/kW) to the utility over the analysis period, in dollars. Costs are escalated at the specified utility cost escalation rate, and then discounted back to the present using the specified discount rate.

Total Utility Fixed Cost
□ - Expected lifecycle cost of fixed payments (on monthly and annual bases) to the utility over the analysis period, in dollars. Costs are escalated at the specified utility cost escalation rate, and then discounted back to the present using the specified discount rate.

Total Utility Minimum Cost Adder

□ - These costs are added to all other utility costs in order to meet the utility's minimum charge requirements on a monthly or annual basis.

REopt Lite constrains the annual sales to the overall annual load on a kWh basis. In other words, the site gets paid (with or without net-metering) by selling energy at the "wholesale" rate, for less than or equal to the site-load. The "utility minimum cost adder" has been put in place to account for a situation where the utility rates chosen might have otherwise allowed the site to make a profit in energy sales.

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Total System and Life Cycle Utility Cost – After Tax

Life Cycle Energy Cost

□ - The present value of costs, after taxes and incentives associated with each project option. For the Business as Usual case, this includes only the utility demand and energy costs and future operation and maintenance costs for any existing PV and/or generator. In a scenario where a critical load is fully met by an existing generator, then this calculation also includes the fuel and operating cost of using that existing generation capacity to meet the outage. For the Financial or Resilience case, this includes the utility demand and energy costs as well as the capital expenditure, tax benefits and incentives, and O&M costs associated with the PV, wind, battery, and total generator project (if recommended). Note that fixed fees charged by the utility are not included, and therefore the actual lifecycle cost of energy may be higher if the utility charges fixed fees. However, because fixed fees cannot be offset by PV, wind, and battery, these net out in the calculation of net present value.

Net Present Value

□ - The present value of the savings (or costs if negative) realized by the project. This is calculated as the difference between the "Business As Usual" case lifecycle energy cost and the "Resilience Case" life cycle energy cost or the "Financial Case" life cycle energy cost.

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Download ProForma Spreadsheet

Selecting this link will download a ProForma spreadsheet.

The first tab of the downloaded spreadsheet includes the Commercial Inputs and Outputs of the evaluated scenario. It provides calculated annual values for each year of the analysis for energy, electric bill, credits, savings, and depreciation values.

A second tab for the Commercial Cash Flow includes values for each year of the analysis period for production, savings, operating expenses, project debt, pretax cash flow, direct cash incentives, federal income tax, and life cycle cost calculations.

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Effect of Resilience Costs and Benefits

This waterfall chart is included in the Result when a Resilience Optimization has been selected. This interactive chart allows the user to consider the cumulative effect of extra costs and benefits of increased resilience on the project's net present value (NPV). Upgrading the recommended system to a microgrid allows a site to operate in both grid-connected and island-mode. This requires additional investment, which may include extra equipment such as controllers, distribution system infrastructure and communications upgrades. Economic benefit is observed when the value of avoiding the costs of an outage are considered. These microgrid upgrade costs and avoided outage costs are not factored into the optimization results. The sliders under the chart allow the user to change the Microgrid Upgrade Cost and the Avoided Outage Costs to analyze the impact on the NPV after Microgrid Costs and Benefits, while the NPV Before Microgrid Investment, which is determined by the optimization results, remains static.

Microgrid Upgrade Cost

□ - The Microgrid Upgrade Cost is not factored into the optimization but appears in this chart of costs and benefits. In order to gain resiliency, the PV/wind/battery/generator must be installed as an island-able system. This incurs additional costs above a typical grid-connected system, which are not included in the economics of the primary optimization. Depending on current site equipment, additional components required may include a manual or automatic transfer switch, critical load panel, and additional controls capabilities in the inverter for islanded operation. Use the slider to select the expected cost of the microgrid upgrade as a percentage of the capital cost of the system.

Avoided Outage Costs

□ - The Avoided Outage Cost is not factored into the optimization but appears in this chart of costs and benefits. This is the value that the user places on the unmet site load during grid outages, or the losses that the site would experience if the load were not met. Units are US dollars per unmet kilowatt-hour. The value of lost load (VoLL) is used to determine the avoided outage costs by multiplying VoLL [$/kWh] with the average number of hours that the critical load can be met by the energy system (determined by simulating outages occurring at every hour of the year), and multiplying by the mean critical load. Use the slider to select the expected VoLL. The Interruption Cost Estimate (ICE) Calculator is a tool designed to aid in estimating interruption costs and/or the benefits associated with reliability improvements.

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Your Inputs

This section shows the inputs used in the analysis. If the default value for an input has been overridden, the original default will be displayed to the right of the user-entered input. There is a link to return to the input page and edit these inputs to evaluate another scenario.

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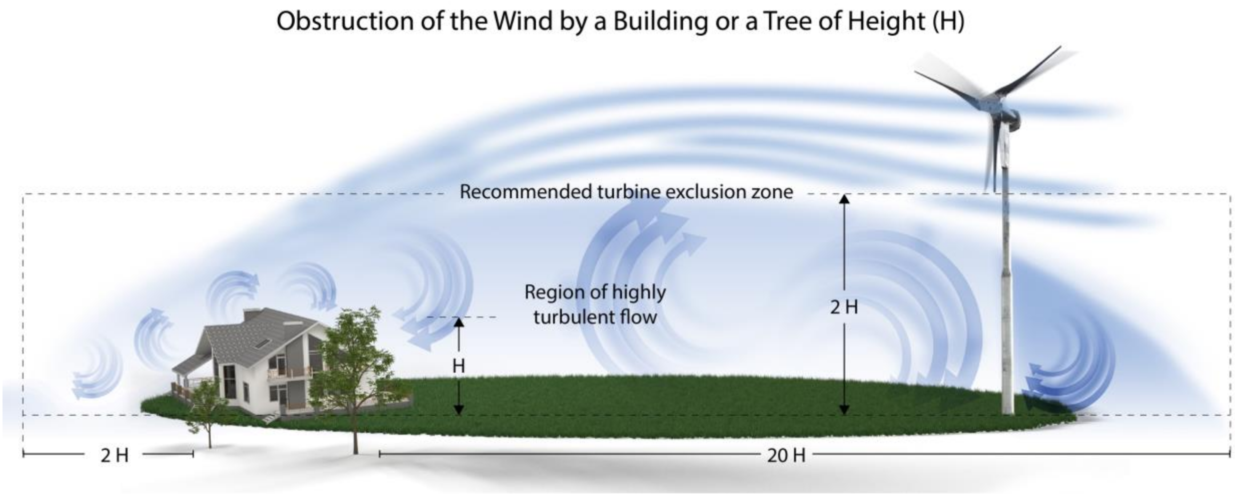
Caution

These results assume perfect prediction of both solar irradiance, wind speed, and electrical load. In practice, actual savings may be lower based on the ability to accurately predict solar irradiance, wind speed, and load, and the battery control strategy used in the system. And, when modeling an outage the results assume perfect foresight of the impending outage, allowing the battery system to charge in the hours leading up the outage.

The results include both expected energy and demand savings. However, the hourly model does not capture inter-hour variability of the PV and wind resource. Because demand is typically determined based on the maximum 15-minute peak, the estimated savings from demand reduction may be exaggerated. The hourly simulation uses one year of load data and one year of solar and wind resource data. Actual demand charges and savings will vary from year to year as load and resource vary.

Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules.

Wind performance predictions are approximate only. Actual wind turbine performance is greatly affected by obstacles surrounding the turbine, including trees, buildings, silos, fences, or any other objects that could block the wind flow. Looking at an energy rose for the site is the best way to estimate the impact of local terrain and obstacles on the potential turbine energy production; the following figure gives a rule of thumb for where not to install a wind turbine (wind from the left).



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Next Steps

This model provides an **estimate** of the techno-economic feasibility of solar, wind, and battery, but investment decisions should not be made based on these results alone. **Before moving ahead with project development, verify:**

- The utility rate tariff is correct.
    - Note that a site may have the option or may be required to switch to a different utility rate tariff when installing a PV, wind, or battery system.
    - Contact your utility for more information.
- Actual load data is used rather than a simulated load profile.
- PV, wind, and battery costs and incentives are accurate for your location. There may be additional value streams not included in this analysis such as ancillary services or capacity payments.
    - There may be additional value streams not included in this analysis such as ancillary services or capacity payments.
- Financial inputs are accurate, especially discount rate and utility escalation rate.
- Other factors that can inform decision-making, but are not captured in this model, are considered. These may include:
    - roof integrity
    - shading considerations
    - obstacles to wind flow
    - ease of permitting
    - regulatory and zoning ordinances
    - utility interconnection rules
    - availability of funding.

Contact NREL at reopt@nrel.gov for more detailed modeling and project development assistance.

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REopt Lite Web Tool Default Values

REopt Lite Default Values, Typical Ranges, and Sources

FINANCIAL			
Input	**Default Value**	**Range**	**Source**
Analysis period (years)	25	10 – 40	**2019 Annual Technology Baseline and Standard Scenarios. NREL, 2019.** https://atb.nrel.gov/ Defaults for Economic lifetime of distributed commercial renewable technologies used for NREL analyses vary. The 2019 ATB includes options for 20 or 30 years. Typical internal REopt analyses use 25 years. **ASTM E917-17, Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, ASTM International, West Conshohocken, PA, 2017** www.astm.org This ASTM standard uses a 25-year study period for most examples. NREL's System Advisory Model (SAM) uses a 25-year analysis period default. November 2019. https://sam.nrel.gov **Energy Independence and Security Act of 2007, Sec. 441. Public Law 110-140, 110th US Congress.** https://www.gpo.gov/fdsys/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf Public building lifecycle costs are evaluated over a 40 year period in federal analyses.
Host discount rate, nominal (%)	8.3%	2 – 15%	**2019 Annual Technology Baseline and Standard Scenarios. NREL, 2019.** https://atb.nrel.gov/

			The NREL 2019 ATB projects a 2019 nominal WACC of 8.3% as a mid-maturity nominal discount rate for Market Factors Financial assumptions to evaluate distributed commercial PV and land-based wind. The projections for 2020 are 8.6% for PV and 8.2% for wind. Discount rate varies significantly between distributed PV and wind adopters. **Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2019 Annual Supplement to NIST Handbook 135. DOE, March 2019.** https://nvlpubs.nist.gov/nistpubs/ir/2019/NIST.IR.85-3273-34.pdf Federal projects use a nominal discount rate of 3.1%.
Host effective tax rate (%)	26% 21%+5%	15 – 21% for federal corporate income taxes plus 0 – 12% state corporate income taxes	**2019 Annual Technology Baseline and Standard Scenarios. NREL, 2019.** https://atb.nrel.gov/ Tax rate (federal and state) used for NREL analyses. **2018 Instructions for Form 1120: U.S. Corporation Income Tax Return. US Department of the Treasury, Internal Revenue Service, January 2019.** https://www.irs.gov/pub/irs-pdf/i1120.pdf Federal corporate income tax rate of a flat 21% is listed under "What's New" on page 1. **State Corporate Income Tax Rates and Brackets for 2019. Tax Foundation, February 2019.** https://files.taxfoundation.org/20190320103634/TaxFoundation_FF639.pdf State corporate income tax rates and brackets listed for 2019. Local income and state and local property taxes should also be taken into account.
Electricity cost escalation rate, nominal (%)	2.3%	1.7 – 2.6%	The nominal electricity cost escalation rate is provided explicitly in the EIA's Annual Energy Outlook and can also be calculated implicitly by combining the NIST Handbook's real electricity cost escalation rates with expected inflation rates. **Annual Energy Outlook 2019 – Electricity Supply, Disposition, Prices, and Emissions. EIA, January 2019.** **https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2019&cases=ref2019&sourcekey=0** The EIA predicts a 2.3% average nominal annual commercial electricity escalation rate from 2020-2045 in

			their reference case scenario, assuming an inflation rate of 1.9%. Regional variation yields a range of annual electricity cost escalation rates from 1.7% to 2.6%.
O&M cost escalation rate (%)	2.5%	-0.2 – 4%.	O&M costs are assumed to escalate at inflation rate. **2019 Annual Technology Baseline and Standard Scenarios. NREL, 2019.** https://atb.nrel.gov/ NREL analyses assume an inflation rate of 2.5%. **Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2019 Annual Supplement to NIST Handbook 135. DOE, March 2019.** https://nvlpubs.nist.gov/nistpubs/ir/2019/NIST.IR.85-3273-34.pdf Federal projects use an inflation rate of 0.1%. **Historical Inflation Rates: 1914-2019. US Inflation Calculator, August 2019.** http://www.usinflationcalculator.com/inflation/historical-inflation-rates/ Lists monthly US inflation rates from 1914-2019. Inflation rate in August 2019 listed as 1.7%. Since 2010, inflation rates have ranged from -0.2% to 3.9%.
PV SYSTEM			
Input	**Default Value**	**Range**	**Source**
System capital cost ($/kW)	$1600	$1246 – 1830	**2019 Annual Technology Baseline and Standard Scenarios NREL, 2019.** https://atb.nrel.gov/ NREL analyses assume a mid-range 2020 distributed commercial PV CAPEX of $1620/kW. **U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018. NREL, November 2018.** https://www.nrel.gov/docs/fy19osti/72399.pdf The resource lists NREL's bottom-up cost calculations for residential, commercial, and utility-scale PV. Commercial PV is calculated to average $1.83/W.
O&M cost ($/kW/year)	$16	$12 –17	**2019 Annual Technology Baseline and Standard Scenarios. NREL, 2019.** https://atb.nrel.gov/ Fixed O&M expenses for distributed commercial PV in 2020 used for NREL analyses.
Array azimuth	180° or 0°	0 - 360°	The default value of 180° assumes the array is in the northern hemisphere and is facing due south. When the

			array is in the southern hemisphere, the assumption is that it is facing due north and the array azimuth default value changes to 0°. **PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts uses a default azimuth of 180° in the northern hemisphere and 0° in the southern hemisphere. **U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018. NREL, November 2018.** https://www.nrel.gov/docs/fy19osti/72399.pdf The resource specifies an array azimuth of 180°.
Array tilt – Rooftop, Fixed	10°	0 – 60°	Rooftop PV is usually mounted at 10-20 degrees on a flat roof to reduce wind loading and shading losses. PV on a sloped roof is typically installed parallel to the roof's surface, though azimuth and tilt angle can be adjusted if desired. **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php For an array installed on a building's roof, you may want to choose a tilt angle equal to the roof pitch. **U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018. NREL, November 2018.** https://www.nrel.gov/docs/fy19osti/72399.pdf The resource specifies an array tilt of 10°. **Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition. 2018.** https://www.nrel.gov/docs/fy19osti/73822.pdf For a ballasted system on a flat roof, a low tilt angle (usually 10° tilt) is required to reduce wind loads.

Array tilt – Ground mount, Fixed	Tilt = latitude	0 – 90°	The default value assumes the tilt is equal to the latitude of the site location. If the site is in the southern hemisphere, this default is the absolute value of the latitude. **PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts uses a default equal to the site latitude. **Advanced Photovoltaic Installations. Balfour, John, Michael Shaw, and Nicole Bremer Nash. The Art and Science of Photovoltaics. 2013.** https://books.google.com/books?id=t5uTktdsu3AC&pg=PA77&lpg=PA77&dq=pv+geometry+flat+roof&source=bl&ots=K4v99ljXqq&sig=spZ0uf0Zdh-zrK66Zldm6UN6ECs&hl=en&sa=X&ved=0ahUKEwiErOjBlevVAhUKw4MKHTzoCMMQ6AEIcDAM#v=onepage&q=pv%20geometry%20flat%20roof&f=false Page 71 describes how in order to maximize annual yield, the array should be tilted at the site's latitude. Decreasing the tilt angle increases summer yield while increasing tilt angle increases winter yield. To maximize output in summer, it should be tilted at (latitude – 15)°. To maximize output in winter, it should be tilted at (latitude + 15) °.
Array tilt – Ground mount, 1-Axis Tracking	0	0° – 10° depending on site slope	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php For arrays with one-axis tracking, the tilt angle is the angle from horizontal of the tracking axis. For flat ground, the tilt would be 0°, or parallel to the ground's surface. For installations that are not on flat ground, the tilt would be the slope of the hillside. **Solar Balance-of-System: To Track or Not to Track, Part 1. Greentech Media,** https://www.greentechmedia.com/articles/read/solar-balance-of-system-to-track-or-not-to-track-part-i 1-axis tracking systems rotate over an axis that is parallel to the ground's surface.
DC to AC ratio	1.2	1.0 – 1.5	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.**

			https://pvwatts.nrel.gov/index.php PVWatts inputs list 1.2 as the default. The help manual also lists a default DC/AC ratio of 1.2. The 2014 technical manual lists a ratio of 1.1.
Incentives	26% ITC, 5 year MACRS 100% Bonus depreciation		**Database of State Incentives for Renewables & Efficiency. NC Clean Energy Tech Center, September 2019.** http://www.dsireusa.org/ http://programs.dsireusa.org/system/program/detail/658 Incentives are available at the federal, state, and local level. This site provides searchable specifics about incentives based on location. The following federal incentives are default values in REopt: **Business Energy Investment Tax Credit (ITC). Database of State Incentives for Renewables & Efficiency, NC Clean Energy Tech Center, March 2018.** http://programs.dsireusa.org/system/program/detail/658 In 2020, a federal 26% investment tax credit is available to solar projects regardless of size, with no maximum incentive for solar technologies. Credit was previously 30%. **Modified Accelerated Cost-Recovery System (MACRS). Database of State Incentives for Renewables & Efficiency, NC Clean Energy Tech Center, August 2018.** http://programs.dsireusa.org/system/program/detail/676 Solar projects are eligible for accelerated depreciation deductions over a 5-year period, with bonus depreciation of 100% in the first year.
System losses – General			Total losses calculated as (1 - (1-loss1)*(1-loss2)*…*(1-lossN))
System losses – Soiling	2%	2 – 25%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default soiling loss of 2%. **Performance Parameters for Grid-Connected PV Systems. NREL, February 2005.** https://www.nrel.gov/docs/fy05osti/37358.pdf Table 1 lists a typical soiling AC derate factor as 0.95, with a typical range of 0.75-0.98. These values correspond to a typical soiling loss of 5% with a typical range of 2-25%.
System losses – Shading	3%	0 – 30%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf

			Current PVWatts online Help Manual. November 2019. https://pvwatts.nrel.gov/index.php PVWatts applies a default shading loss of 3%. **Photovoltaic Shading Testbed for Module-Level Power Electronics: 2016 Performance Data Update. NREL and PV Evolution Labs, September 2016.** https://static1.squarespace.com/static/556efc95e4b0b54303d2a73c/t/5801147a5016e1907a35cf89/1476465790487/PV+Shading+Testbed+Sept+2016.pdf Based on a survey of shading of residential PV systems, this study classifies light shading as <15% annual shading (7.6% is representative of typical light shading), moderate shading as 15-20% annual shading (19% is representative of typical moderate shading), and heavy shading as >20% annual shading (25.5% is representative of typical heavy shading). If the shading increases to >30% of the modules in a string, the MPPT minimum voltage would be reached. **Performance Parameters for Grid-Connected PV Systems. NREL, February 2005.** https://www.nrel.gov/docs/fy05osti/37358.pdf Table 1 lists a typical shading derate factor as 0.975 for fixed-tilt rack-mounted systems. These values correspond to a typical shading loss of 2.5%.
System losses – Snow	0%	0 – 15% typical in US, 0 – 100% possible	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default snow loss of 0%. **Integration, Validation, and Application of a PV Snow Coverage Model in SAM. NREL, August 2017.** https://www.nrel.gov/docs/fy17osti/68705.pdf Figures 2 and 3 show estimated snow losses for cities and regions, respectively, of the US. Appendices A and B provide the respective data in more detail.
System losses – Mismatch	2%	1.5 – 3%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default mismatch loss of 2%. **Performance Parameters for Grid-Connected PV Systems. NREL, February 2005.** https://www.nrel.gov/docs/fy05osti/37358.pdf

			Table 1 lists a typical mismatch derate factor as 0.98, with a typical range of 0.97-0.985. These values correspond to a typical mismatch loss of 2% with a typical range of 1.5-3%.
System losses –Wiring	2%	0.7 – 2%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default wiring loss of 2%. **Performance Parameters for Grid-Connected PV Systems. NREL, February 2005.** https://www.nrel.gov/docs/fy05osti/37358.pdf Table 1 lists a typical wiring derate factor as 0.99, with a typical range of 0.98-0.993. These values correspond to a typical wiring loss of 1% with a typical range of 0.7-2%.
System losses – Connection	0.5%	0.3 – 0.1%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default connection loss of 0.5%. **Performance Parameters for Grid-Connected PV Systems. NREL, February 2005.** https://www.nrel.gov/docs/fy05osti/37358.pdf Table 1 lists a typical diodes and connections derate factor as 0.995, with a typical range of 0.99-0.997. These values correspond to a typical connection loss of 0.5% with a typical range of 0.3-1%.
System losses – Light-induced Degradation (LID)	1.5%	0.3 – 10%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default light-induced degradation loss of 1.5%. **Performance Parameters for Grid-Connected PV Systems. NREL, February 2005.** https://www.nrel.gov/docs/fy05osti/37358.pdf Table 1 lists a typical LID derate factor as 0.98, with a typical range of 0.90-0.99. These values correspond to a typical mismatch loss of 2% with a typical range of 1-10%.
System losses – Nameplate	1%	-5 – 15%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.**

Rating			https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default nameplate rating loss of 1%. **Performance Parameters for Grid-Connected PV Systems. NREL, February 2005.** https://www.nrel.gov/docs/fy05osti/37358.pdf Table 1 lists a typical nameplate rating derate factor as 1.0, with a typical range of 0.85-1.05. These values correspond to a typical nameplate rating loss of 0% with a typical range of -5-15%.
System losses – Age	0%	0 – 100%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default loss due to age of 0%.
System losses – Availability	3%	0.5 – 100%	**PVWatts Version 5 Manual. Dobos, Aron P., NREL, September 2014.** https://www.nrel.gov/docs/fy14osti/62641.pdf **Current PVWatts online Help Manual. November 2019.** https://pvwatts.nrel.gov/index.php PVWatts applies a default availability loss of 3%. **Performance Parameters for Grid-Connected PV Systems. NREL, February 2005.** https://www.nrel.gov/docs/fy05osti/37358.pdf Table 1 lists a typical availability derate factor as 0.98, with a typical range of 0-0.995. These values correspond to a typical availability loss of 2% with a typical range of 0.5-100%.
STORAGE (Note all values listed assume the use of lithium-ion battery systems)			
Input	**Default Value**	**Range**	**Source**
Energy capacity cost ($/kWh)	$420	$335 – 700	**U.S. Energy Storage Monitor: Q3 2019 Full Report. Wood Mackenzie Power & Renewables and the Energy Storage Association (ESA), September 2019.** This analysis starts with Wood Mackenzie's all-inclusive cost of system, installation, normal interconnection, and metering costs to be $1,750/kW for a non-residential behind-the-meter 2-hour system, with a cost range of $1,375 - $2,700/kW. To determine energy capacity and energy demand components of the cost, two methods are employed. If the a

			scaling factor similar to utility size systems for the difference between 2 and 4 hour systems is assumed, then non-residential median costs of \$422/kWh and \$906/kW can be computed. Alternatively, if the system is assumed to have an energy:power ratio of 2:1 (i.e. 2 kWh:1kW), the resulting median costs are approximately \$438/kWh and \$875/kW (with ranges of 344-675 kWh and 688-1350 kW)and if a 1.85:1 ratio is assumed to correspond to front-of the-meter ratios, the resulting median costs are approximately \$455/kWh and \$841/kW (with ranges of 357-701 kWh and 661-1297 kW). **Lazard's Levelized Cost of Storage Analysis. November 2018** https://www.lazard.com/media/450774/lazards-levelized-cost-of-storage-version-40-vfinal.pdf Key Assumptions table gives Initial Capital cost for a 2-hr battery of \$335-580/kWh and \$158-254/kW
Power capacity cost (\$/kW)	\$840	\$158 – 1350	See above description of basis for energy capacity cost.
Battery energy capacity replacement cost (\$/kWh)	\$200	\$162 – 340	**U.S. Energy Storage Monitor: Q3 2019 Full Report. Wood Mackenzie Power & Renewables and the Energy Storage Association (ESA), September 2019.** Woods Mackenzie predicts a decline in price of 20-25% in the next 2 years for front-of-the meter storage, but more flat costs for behind-the-meter, due to supply constraints, in the 1-3% decline range. Once supply constraints are removed, the cost decline is likely to improve. Replacement costs need to be estimated for 10 years out. Conservatively decline may be expected in the 7% per year range. **Energy Storage Technology and Cost Characterization Report. PNNL. July 2019** https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf A cost drop of 5% per year was assumed to be a conservative estimate for batteries on the lower end of the cost range. This is in light of significant cost drops seen in the past 10 years.
Energy capacity replacement year	10	9 – 20	Because the replacement timeline for Li-ion batteries is impacted by the SOC at which it is utilized, the replacement year is difficult to predict. REopt does not currently account for battery degradation or loss of capacity over time in its dispatch and energy/power calculations, but allows the user to input a replacement year. The year 10 replacement

			default assumes that the technology for this replacement will have improved to the point that it will last for the remaining 15 years of the default 25-year analysis period. **Economic Analysis Case Studies of Battery Energy Storage with SAM. NREL, November 2015.** https://www.nrel.gov/docs/fy16osti/64987.pdf Uses the Tesla Powerwall specifications as an example and estimates that it will last 5 years longer than its 10-year warranty. At one cycle per day, this amounts to approximately 5475 cycles. **Energy Storage Technology and Cost Characterization Report. PNNL. July 2019** https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf A survey of the literature suggests the lower end of the typical suggested range of 10-20 life years
Power capacity replacement cost ($/kW)	$410	$76 – $653	See above description of basis for energy capacity replacement cost.
Power capacity replacement year	10	9 – 20	See above description of basis for energy capacity replacement year.
Rectifier efficiency (%)	96%		**An integrated approach for the analysis and control of grid connected energy storage systems. Journal of Energy Storage, Volume 5, February 2016.** http://www.sciencedirect.com/science/article/pii/S2352152X15300335 Depending on the SOC, the converter efficiency of a 100kW/50kWh lithium-ion system was found to sit around 96% for SOCs of 30-100%, as illustrated in Figure 14. The efficiency of this converter is applied to both the inverter and rectifier in REopt.
Round trip efficiency (%)	97.5%	95 – 98%	**An integrated approach for the analysis and control of grid connected energy storage systems. Journal of Energy Storage, Volume 5, February 2016.** http://www.sciencedirect.com/science/article/pii/S2352152X15300335 Depending on the SOC, the battery efficiency of a 100kW/50kWh lithium-ion system was found to vary between 97-98% for SOCs of 30-100%, as illustrated in Figure 14.

			Lithium Batteries and Other Electrochemical Storage Systems. Glazie, Christian and Geniès, Sylvie, August 2013. http://onlinelibrary.wiley.com/doi/10.1002/9781118761120.ch6/pdf The efficiency depends on the battery's state of charge and it's charge/discharge conditions (voltage, rate of charge/discharge, temperature), especially at high or low SOC. The following values give average efficiencies at mid-range SOCs. 95% for C-$LiFePO_4$ – see section 6.2.18. 98% for C-$Li(Co,Ni)O_2$ – see section 6.2.18.
Inverter efficiency (%)	96		**An integrated approach for the analysis and control of grid connected energy storage systems. Journal of Energy Storage, Volume 5, February 2016.** http://www.sciencedirect.com/science/article/pii/S2352152X15300335 Depending on the SOC, the converter efficiency of a 100kW/50kWh lithium-ion system was found to sit around 96% for SOCs of 30-100%, as illustrated in Figure 14. The efficiency of this converter is applied to both the inverter and rectifier in REopt.
Minimum state of charge (%)	20	15 – 30%	**An integrated approach for the analysis and control of grid connected energy storage systems. Journal of Energy Storage, Volume 5, February 2016.** http://www.sciencedirect.com/science/article/pii/S2352152X15300335 When the state of charge of a lithium-ion battery drops below 20%, the voltage drops rapidly and impedance, which reduces round trip efficiency and generates heat, so optimal performance is achieved above 20% SOC.
Incentives	0% ITC, 7 year MACRS 100% Bonus depreciation		**Database of State Incentives for Renewables & Efficiency. NC Clean Energy Tech Center, September 2019.** http://www.dsireusa.org/ http://programs.dsireusa.org/system/program/detail/658 Incentives are available at the federal, state, and local level. This site provides searchable specifics about incentives based on location. The following federal incentives are default values in REopt: The Federal ITC credit for batteries **Business Energy Investment Tax Credit (ITC). Database of State Incentives for Renewables & Efficiency, NC Clean Energy Tech Center, March 2018.** http://programs.dsireusa.org/system/program/detail/658

			The default for percentage-based incentives is $0, corresponding to the default of the battery charging from the grid. New Tax laws concerning battery systems are pending. Please consult current rules. The 2020 Federal 26% investment tax credit is generally understood to be available to batteries charged 100% by eligible RE technologies, including solar and wind, when they are installed as part of a renewable energy system. Batteries charged by a RE system 75%-99% of the time are eligible for that portion of the ITC. For example, a system charged by RE 80% of the time is eligible for the 26% ITC multiplied by 80%, which equals a 20.8% ITC instead of 26%. **Federal Tax Incentives for Energy Storage Systems. National Renewable Energy Laboratory. January 2018.** https://www.nrel.gov/docs/fy18osti/70384.pdf Batteries charged at least 75% by eligible RE technologies are eligible for accelerated depreciation deductions over a 5-year period, with a bonus depreciation of 100% in the first year. Batteries charged 0-75% by RE are eligible for a 7-year depreciation schedule.
WIND SYSTEM			
Input	**Default Value**	**Range**	**Source**
Wind size class	Comm – (21-100 kW	2.5 kW–2,000 kW	Wind Class size options, and the representative turbine sizes, are Residential 0-20 kW (2.5 kW), Commercial 21-100 kW (100 kW), Midsize 101-999 kW (250 kW) and Large >= 1000 kW (2,000 kW). **2018 Distributed Wind Market Report.** Alice Orrell, Danielle Preziuso, Nik Foster, Scott Morris, and Juliet Homer of Pacific Northwest National Laboratory. August 2019. https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Distributed%20Wind%20Market%20Report.pdf **Benchmarking US Small Wind Costs with the Distributed Wind Taxonomy**. AC Orrell and EA Poehlman. Pacific Northwest National Laboratory. September 2017. https://wind.pnnl.gov/pdf/Benchmarking_US_Small_Wind_Costs_092817_PNNL.pdf
System capital cost ($/kW) Class	Comm – $7390	Res – $11,950 Comm – $7,390 Midsize –	Wind CAPEX Defaults change depending on the Wind Class size chosen: Residential ($11,950/kW), Commercial ($7,390/kW), Midsize ($4,440/kW) and Large ($3,450/kW). If no Wind Class is chosen, the default is the Commercial size, which has a default of $7,390.

		$4,440 Large – $3,450	**Benchmarking US Small Wind Costs** gives 2016 values for Residential $11,953, Commercial $7,389 **Benchmarking US Small Wind Costs with the Distributed Wind Taxonomy**. AC Orrell and EA Poehlman. Pacific Northwest National Laboratory. September 2017. https://wind.pnnl.gov/pdf/Benchmarking_US_Small_Wind_Costs_092817_PNNL.pdf **Distributed Wind Market Report** gives average for small wind <100 kW of 2017 $10,030/kW and average for >100 kW of 2018 $4,437/kW. The Distributed Wind Market Report does not include a cost for large turbines, but the database used for the report indicates an average for single large turbine projects in 2016/2017 of $3,450. **2018 Distributed Wind Market Report.** Alice Orrell, Danielle Preziuso, Nik Foster, Scott Morris, and Juliet Homer of Pacific Northwest National Laboratory. August 2019. https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Distributed%20Wind%20Market%20Report.pdf **Wind Technologies Market Report** gives average installed project costs of $1,743/kW for turbines in the 1,500-2,000 kW size range, but these represent larger installations that could take advantage of economies of scale. **2018 Wind Technologies Market Report.** Ryan Wiser and Mark Bolinger. Lawrence Berkeley National Laboratory. August 2019. https://www.energy.gov/eere/wind/downloads/2018-wind-technologies-market-report **2019 Annual Technology Baseline and Standard Scenarios. NREL, 2019.** https://atb.nrel.gov/ The NREL ATB projects 2020 CAPEX of $1,540, but this also assumes a large installation.
O&M cost ($/kW/year)	$40	$18–$59	Distributed Wind Market Report uses $40/kW/yr with reference to NREL's Assessing the Future of Distributed Wind 2016 values of $30-$40. **2018 Distributed Wind Market Report.** Alice Orrell, Danielle Preziuso, Nik Foster, Scott Morris, and Juliet Homer of Pacific Northwest National Laboratory. August 2019.

			https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Distributed%20Wind%20Market%20Report.pdf **2019 Annual Technology Baseline and Standard Scenarios. NREL, 2019.** https://atb.nrel.gov/ The NREL 2019 ATB projects a 2020 O&M cost of $42/kW/yr. Wind Technologies Market Report gives a $33-$59 range with a mid-point of $44/kW/yr. **2018 Wind Technologies Market Report.** Ryan Wiser and Mark Bolinger. Lawrence Berkeley National Laboratory. August 2019. https://www.energy.gov/eere/wind/downloads/2018-wind-technologies-market-report
Incentives	26% ITC for small wind to 100 kW and 0% for larger wind, 5 year MACRS, 100% bonus depreciation		**Database of State Incentives for Renewables & Efficiency. NC Clean Energy Tech Center, September 2019.** http://www.dsireusa.org/ http://programs.dsireusa.org/system/program/detail/658 Incentives are available at the federal, state, and local level. This site provides searchable specifics about incentives based on location. The following federal incentives are default values in REopt: **Business Energy Investment Tax Credit (ITC). Database of State Incentives for Renewables & Efficiency, NC Clean Energy Tech Center, March 2018.** http://programs.dsireusa.org/system/program/detail/658 In 2020, a federal 26% investment tax credit is available to wind projects up to 100kW in capacity. The ITC is discontinued in 2020 for larger wind systems. **Modified Accelerated Cost-Recovery System (MACRS). Database of State Incentives for Renewables & Efficiency, NC Clean Energy Tech Center, August 2018.** http://programs.dsireusa.org/system/program/detail/676 Wind projects are eligible for accelerated depreciation deductions over a 5-year period, with bonus depreciation of 100% in the first year. The provision which defines ITC technologies as eligible also adds the general term "wind" as an eligible technology, extending the five-year schedule to large wind facilities as well.

RESILIENCE EVALUATIONS - LOAD PROFILE			
Input	**Default Value**	**Range**	**Source**

Critical load factor (%)	50%	10–100%	The critical load varies widely based on building use.
RESILIENCE EVALUATIONS - GENERATOR			
Input	**Default Value**	**Range**	**Source**
Install cost ($/kW)	$500	$238-$800	**2019 RSMeans Building Construction Cost Data. 77th Annual Edition. Gordian Group. Reference: Packaged Generator Assemblies. Engine Generators. Diesel-Engine-Driven Generator Sets.** Total installing contractor costs, including overhead and profit, range from $238/kW for a 500 kW system to $527/kW for a 30 kW system. **Lazard's Levelized Cost of Energy Analysis—Version 11.0. November 2017.** (NOTE: 2018 version doesn't include diesel analysis) https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf For an output of 250-1000 kW, the total capital costs average $500-$800/kW. Costs may assume Tier 4 compliance costs of adding emission control systems for prime applications as well as emergency backup.
Diesel cost ($/gal)	$3	$2.50-$3.27	**Cost Reference Guide for Construction Equipment: The Standard Reference for Estimating Owning and Operating Costs for all Classes of Construction Equipment. 1st Half 2019. EquipmentWatch.** Diesel = $3.27/gal **Lazard's Levelized Cost of Energy Analysis—Version 11.0. November 2017.** (NOTE: 2018 version doesn't include diesel analysis) https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf Diesel price of ~$2.50/gal
Fuel availability (gallons)	660	1.4-660	National Fire Prevention Association code NFPA 110: Standard for Emergency and Standby Power Systems, 2019 Edition, Section 110-17 7.9.5. Integral tanks up to a maximum of 660 gallons for diesel fuel are permitted inside or on roofs of structures. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=110 Some critical facilities such as hospitals are required to have 96 hours of fuel. Users can change the default depending on their building requirements. https://www.facilitiesnet.com/healthcarefacilities/article/NFPA-110s-Fuel-Requirements-Can-Help-Guide-Backup-

			Power-Plan-For-Hospitals--14338
Fixed O&M ($/kW/yr)	$10	$10-$35	**Lazard's Levelized Cost of Energy Analysis—Version 11.0. November 2017.** (NOTE: 2018 version doesn't include diesel analysis) https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf For an output of 250-1000 kW, the Key Assumptions table lists a fixed O&M at $10/kW/yr. For a back-up generator, these costs are assumed to be small, primarily based on regular monthly maintenance.
Variable O&M ($/kWh)	$0.00	$0.005 - $0.01	**Lazard's Levelized Cost of Energy Analysis—Version 11.0. November 2017.** (NOTE: 2018 version doesn't include diesel analysis) https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf For an output of 250-1000 kW, the Key Assumptions table lists a variable O&M of $0.01/kWh. However, these cited costs are based on regular generator use. The generator modeled in REopt Lite is a backup generator, with limited use, therefore the default for these costs is set to $0/kWh. The user can set a higher value if the generator will be used more extensively. **Gas Technology Institute** (GTI) referenced in FacilitiesNet. October 2019. https://www.facilitiesnet.com/powercommunication/article/Onsite-Options--1679
Fuel burn rate by generator capacity (gal/kWh)	0.076	0.069-0.172	**Diesel Service and Supply Website: Approximate Diesel Fuel Consumption Chart.** October 2019 https://www.dieselserviceandsupply.com/Diesel_Fuel_Consumption.aspx A constant specific fuel consumption rate default across generator sizes and load conditions is used due to fuel's relatively small percentage of the lifecycle cost for a generator used only as backup power in a grid outage and also due to the resulting significant positive impact on solution times. The median value across a size range of 20 kW to 2250 kW and a load range of 25% to 100% was selected as representative.
Fuel curve y-intercept by generator capacity (gal/hr)	0	0-0.71	Since a constant specific fuel consumption rate was chosen as the default across generator sizes and load conditions, the corresponding y-intercept value is assumed to be 0. The input field is retained to allow for custom y-intercept entries.

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REopt Technical Reference

REopt: A Platform for Energy System Integration and Optimization provides technical details of the full REopt model. This manual provides a summary of elements relevant to REopt Lite; please consult the REopt Technical Report for details.

Model Overview

The REopt model is a techno-economic decision support model used to optimize energy systems for buildings, campuses, communities, and microgrids. Formulated as a mixed-integer linear program, REopt solves a deterministic optimization problem to determine the optimal selection, sizing, and dispatch strategy of technologies chosen from a candidate pool such that loads are met at every time step at the minimum life cycle cost. REopt is a time series model in which energy balances are ensured at each time step (often in 15-minute or 1-hour intervals) and operational constraints are upheld while minimizing the cost of energy services for a given customer. A primary modeling assumption is that decisions made by the model will not impact the markets; i.e., the model is always assumed to be a price-taker. This is in contrast to unit commitment and dispatch models in which pricing is a decision variable. REopt does not model power flow or transient effects.

REopt solves a single year optimization to determine N-year cash flows, assuming constant production and consumption over all N years of the desired analysis period. REopt assumes perfect prediction of all future events, including weather and load.

For more details, refer to the REopt Technical Report.

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Mixed Integer Linear Program Formulation

REopt solves a Mixed-Integer Linear Program (MILP), the general form of which is given in the REopt Technical Report.

The objective function in the REopt model minimizes total life cycle cost, which consists of a set of possible revenues and expenses, over the analysis period subject to a variety of integer and non-integer constraints to ensure that thermal and electrical loads are met at every time step by some combination of chosen technologies. A qualitative overview of the components of the objective function as well as the main constraint categories within the MILP are given here; for detailed mathematical formulation, see the REopt Technical Report.

Objective Function

The objective function of the MILP is to minimize the present value of all energy costs during the analysis period. Costs considered include:

- Capital costs: Investments made to acquire new energy generation capacity, storage units, and other auxiliary equipment
- Operating expenses: Fixed and variable technology operations and maintenance (O&M) costs, equipment replacement costs, fuel costs, utility purchases, and financial losses incurred due to grid outages
- Operating revenues: Net metering income, wholesale electricity sales, and production-based incentives
- Incentives and tax benefits: Federal, state, and utility incentives, accelerated depreciation schedules
- Cash flows: Found during the analysis period by first escalating the present costs at project-specific inflation and utility cost escalation rates, then discounting back to the present using a client-determined discount rate.

Constraints

The constraints governing how REopt builds and dispatches technologies fall into the following categories:

- Load constraints: Loads must be fully met by some combination of renewable and conventional generation during every time step. Typically, hourly or 15-minute time steps are used in the model. Additional load constraints restrict the amount of energy that a particular technology can replace.
- Resource constraints: The amount of energy that a technology can produce is limited by the amount of resource available within a region or by the size of fuel storage systems. The energy production of variable technologies is limited by the renewable resource at the location, while the utility grid is assumed to be able to provide unlimited amounts of energy.
- Operating constraints: Dispatchable technologies may have minimum turndown limits that prevent them from operating at partial loads less than a specified level. Other operating constraints may limit the number of times a dispatchable technology can cycle on and off each day, or impose minimum or maximum state of charge requirements on battery technology.

- Sizing constraints: Most sites have limited land and roof area available for renewable energy installations, which may restrict the sizes of technologies like PV or wind. The client may also specify acceptable minimum and maximum technology sizes as model inputs.
- Policy constraints: Utilities often impose limits on the cumulative amount of renewable generation a site can install and still qualify for a net metering agreement. Other policy constraints may restrict the size of a variable technology system in order for it to be eligible for a production incentive.
- Scenario constraints (optional): Constraints may require a site to achieve some measure of energy resiliency by meeting the critical load for a defined period of time with on-site generation assets.

For more details, refer to the REopt Technical Report.

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Temporal Resolution

REopt uses time series integration to combine the energy production from concurrently operating technologies. The optimization model assumes that production and consumption are constant across all years of analysis, and so only considers the energy balance of Year 1. The typical time step is one hour, resulting in 8,760 time steps in a typical N-year analysis. This ensures that seasonal variation in load and resource availability is captured.

For more details, refer to the REopt Technical Report.

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Resource Data

REopt automatically queries NREL's Geographic Information System databases to gather renewable energy resource data. This information is used to calculate the production profiles of various technologies. REopt uses hourly solar irradiance values from TMY2 data from the 1991–2005 National Solar Radiation Database. REopt Lite uses wind resource data from the Wind Integration National Dataset (WIND) Toolkit. For more details about the resource data used, refer to the REopt Technical Report.

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Incentives

REopt considers available federal, state, and local incentives, including cost-based incentives, production-based incentives, and tax incentives. Cost-based incentives are modeled in units of dollars per kilowatt or percent of installed cost, and a maximum total incentive value and maximum system size may be specified. Production-based incentives are modeled in units of dollars per kilowatt-hour generated per year and a maximum number of years the incentive is available. A maximum incentive value per year and system size may be specified, and net metering benefits are also considered.

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Rate Tariffs

REopt supports complex tariff structures that include both peak demand charges and time-of-use (TOU) consumption rates. Demand rates may be specified for on-peak and off-peak hours, which can vary by season. TOU consumption rates may vary by the time of day, the season, or both. Rates are queried from the OpenEI Utility Rate Database. For more details, refer to the REopt Technical Report.

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Economic Model

The economic cost-benefit analysis within REopt is based on general economic theory. The approach and terminology are based on the *Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies* (Short, Packey, and Holt 1995) and abides by the life cycle cost methods and criteria for federal energy projects as described in the Federal Code of Regulations 10 CFR Part 436 - Subpart A, and which are detailed in NIST Handbook 135, Life-Cycle Costing Manual for the Federal Energy Management Program (Fuller and Petersen 1995). For more details, refer to the REopt Technical Report.

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PV Model

REopt uses NREL's PVWatts® application to determine the electricity production of installed PV systems. The amount of electricity produced by the PV array at each time step is proportional to the hourly capacity factor at the site. Because the production of PV arrays tends to decline over their lifespan, and the model only optimizes over one year, REopt calculates an annual production profile that has an economic equivalent production profile with 0.5%/year degradation over the analysis period. This is done by applying the ratio of geometric series present worth factor (with degradation included) and uniform series present worth factor to calculate the economic equivalent profile.

Refer to the PVWatts technical reference manual for further modeling assumptions and descriptions (Dobos 2014).

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Wind Model

REopt Lite uses the site location and the wind size class selected to access wind resource data from the Wind Integration National Dataset (WIND) Toolkit. The WIND Toolkit includes meteorological conditions and turbine power for more than 126,000 sites in the continental United States for the years 2007–2013. REopt Lite uses 2012 data because it is close to the WIND Toolkit overall average wind generation across 2007-2013.

The Wind Toolkit provides wind speed, air pressure, air temperature, and wind direction at an hourly resolution. These values returned by the WIND Toolkit are processed by the System Advisor Model (SAM) to produce the wind energy production curves used for the optimization (https://sam.nrel.gov).

Refer to the WIND Toolkit technical reference manual for further modeling assumptions and descriptions (*Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit*). For more details, refer to the REopt Technical Report.

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Battery Model

Energy storage is modeled as a “reservoir” in REopt—energy produced during one time step can be consumed during another. REopt does not explicitly model battery chemistries, but rather imposes heuristic constraints that are designed to ensure the battery operates within the manufacturer’s specifications. A round-trip efficiency is assumed and limits are imposed on the minimum state of charge, charging and discharging rates, and the number of cycles per day. The model is able to select and size both the capacity of the battery in kWh and the power delivery in kW. By default, any technology can charge the energy storage device, but charging can also be limited to specific technologies.

For more details, refer to the REopt Technical Report.

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Resiliency Analysis

Due to the explicit modeling of the utility grid within REopt, the model can be used to simulate grid outages by turning off the grid for certain time steps. The load profile can also be modified during these grid outages to represent a "critical" load (either via a % scaling factor or by splicing in a critical load). This enables evaluation of all technologies in the model, both during grid-connected mode (vast majority of the year) and during grid outages. This capability is especially important for renewable energy technologies, because they are able to generate value during grid-connected mode while also supporting a critical load during a grid outage (whereas backup generators may only be able to operate during an outage due to air quality permits). For more details, refer to the REopt Technical Report.

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For Developers

The National Renewable Energy Laboratory's developer network helps software developers to access and use energy data via web services, including renewable energy and alternative fuel data. The network's home page is at developer.nrel.gov. Nonprofit or commercial use of these web services is free, subject to hourly and daily limits on the number of web service requests as described at developer.nrel.gov/docs/rate-limits. The REopt Lite Web Tool application programming interface (API) is available on the NREL developer network. The API allows users and software developers to programmatically interface with the REopt Lite web tool. The API can be used to evaluate multiple sites and perform sensitivity analyses in an efficient manner, and integrate REopt Lite capabilities into other tools. Access the API.

The developer network website includes the following resources:

- Documentation of the services available in different categories
- Sign-up form to get an API key required to use the services
- Contact options.

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About

The REopt Lite Web Tool currently evaluates the economic viability of grid-connected PV, wind and battery storage at a site. It allows building owners to identify the system sizes and battery dispatch strategy that minimize their life cycle cost of energy. This web tool also estimates the amount of time a PV and/or wind plus battery system can sustain the site's critical load during a grid outage.

It is a free, publicly available web version of the more comprehensive REopt tool, which provides concurrent, multiple technology integration and optimization capabilities to help organizations meet their cost savings and energy performance goals.

Under development at NREL since 2007, the full REopt tool was initially created to identify and prioritize cost-effective renewable energy projects across a portfolio of sites. The model is now also used to optimize the size and operating strategy of microgrids, storage, and energy/water systems. REopt analyses have led to more than 260 MW of renewable energy development.

The full REopt tool is currently used exclusively by NREL analysts in the provision of project feasibility analysis support to clients. Formulated as a mixed integer linear program, REopt recommends an optimally sized mix of renewable energy, conventional generation, and energy storage technologies; estimates the net present value of implementing those technologies; and provides a dispatch strategy for operating the technology mix at maximum economic efficiency.

Enabling free public access to a subset of REopt capabilities will allow a broader audience to run their own site-specific, optimized, and integrated renewable energy decision analysis. This will accelerate renewable energy project development and deployment by greatly expanding access to the REopt capabilities and allowing users to implement some of their project feasibility assessments on their own.

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Feedback

Contact NREL at REopt@nrel.gov to offer suggestions or feedback on the REopt Lite Web Tool, or to explore options for more detailed modeling and project development assistance.

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